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A Review of Current British Thinking on Water Supply

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A review, prepared as a service to the water works field.

IN the past several years much constructive thinking has been done in Great Britain and Northern Ireland on the subject of water supply. Reviewed here are the following British reports, bills, and papers which, in the author's opinion, illustrate the trend of British opinion on the subject.*

(1) Report of the Committee on Land Utilization in Rural Areas, August 1942
(2) First and Second Postwar Reports of the British Waterworks Association on Control of Water Resources
(3) The Postwar Water Supply Report of the Institution of Water Engineers
(4) The Rural Water Supply and Sewerage Bill
(5) The Agriculture (Miscellaneous Provisions) Bill
(6) Water Supply and Sewerage in Northern Ireland, September 1943
(7) National Water Policy Paper presented by the Government to Parliament in April 1944
(8) The Statement of the Labor Party of its Postwar Water Policy

Report of the Committee on Land Utilization in Rural Areas

This Committee, headed by the Rt. Hon. Lord Justice Scott, P.C., as Chairman, was appointed in October 1941 by the Minister of Works and Buildings, in consultation with the Minister of Agriculture:

> To consider the conditions which should govern building and other constructional development in country areas consistently with the maintenance of agriculture, and in particular the factors affecting the location of industry, having

* Persons interested in the availability and price of these documents should write for information to the British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.

regard to economic operation, part-time and seasonal employment, the well-being of rural communities and the preservation of rural amenities.

The scope of the study was confined to England and Wales but did not include Scotland. It presented its report to the Minister of Works and Planning in July 1942 and was in turn presented by him to Parliament in August 1942. Professor S. R. Dennison did not agree with the majority and filed a minority report which is published with that of the majority.

Although the whole report is of a most interesting and informative nature, this review is confined to that part of it relating directly to water works. The report sets forth factual data relative to the distribution of land areas and population in England and Wales; a description of the countryside and an explanation of the factors that created it; changes in agriculture during the several decades preceding the war with the reasons for the changes; and the remedial measures attempted to improve conditions in the rural areas.

In connection with the explanation of the factors creating the countryside, it is interesting to note the statement to the effect that the site of many villages was chosen because of the presence of an essential water supply in the way of a spring or a stream, while others were chosen on lowland knolls in order to be out of the way of floods. One of the significant features in connection with agriculture is the drift of the population away from the land, the decrease in the number of agricultural workers being over 25 per cent between 1921–24 and 1938. One of the major reasons for the drift was the more attractive living facilities and greater amenities of town life. There was a serious shortage of houses for farm workers and those available had low standards of accommodation, equipment and services. Thousands of cottages had no piped water supply and to quote the report, "For the great majority of rural workers a bathroom is a rare luxury." Considerable effort has been made to improve these living conditions in the way of housing and services. Under the Rural Water Supply Act of 1934 about one million pounds was expended by the government to assist in extending piped water supplies to rural areas. This government grant resulted in a total expenditure of between six and seven million pounds for the above purpose. There still exists, however, a grave deficiency in rural water supply. It was estimated in 1939 that 3,432 parishes of England and Wales were entirely without a piped water supply. The drift from the country to the town resulted also in the push of the town out into the country. Graphs showing the increase in land occupied by urban development in counties affected by the expansion of London are included in the report.

While the opinion of the majority of the committee is that the impact of industry on the countryside did more harm than good before the war, certain witnesses suggested, among other benefits resulting from the introduction of industry in the rural areas, that "electricity, water supply and sometimes gas, as well as some system of sewage disposal, are necessary to factories, and the country areas round about benefit from the introduction of these services." A statement was also made that "If the introduction of industry into rural areas were to be properly and carefully directed, some of the former difficulties and drawbacks might be overcome, or at any rate mitigated, while

some of the advantages might be more fully realized."

It should be noted in discussing postwar trends the conclusion is reached that the former prewar trend of the diffusion of constructional development into country areas will reassert itself after the war unless checked and directed.

In connection with the committee's recommendations as to measures to be taken for the revivification of country areas it makes the following interesting statement relative to housing.

> The provisions of electricity, gas, tap water and sewerage systems are separately considered, but we consider that new houses should be built ready-wired for electricity and appropriately constructed to receive gas and water supplies even if these services are not immediately available.

The recommendations of the committee as to water supply are sufficiently important and interesting to warrant their being given here in full.

> *Water.*—We consider the provision of a piped water supply an essential service in every village and on every farm and a desideratum in every dwelling. We do not, however, consider that the provision of a piped supply to villages necessarily involves the linking up with a large supply system, since the application of electricity to pumping should often make available local underground supplies. At present the absence of adequate supplies from any source is a serious deterrent to efficient farming on many farms and the provision of electricity will thus perform this as well as its other useful functions.
>
> We note with approval the steps which are being taken by the Ministry of Agriculture to assist in the provision of water to farms.
>
> We recognize that the water supply companies regard with the utmost seriousness their primary duty to the nation of maintaining the purity of their water supply and agree that this function must come first. At the same time, we consider that a diversity of existing practice indicates that several matters of vital interest could well be reviewed. We accordingly recommended that the Ministries of Health and Agriculture, in conjunction with the industry and in consultation with the Central Planning Authority, should review the whole position of water supply from the national point of view with special reference to the following matters, among others:
>
> (a) the provision of a main supply to all towns and larger villages not at present supplied.
>
> (b) what reorganization of areas of supply, public or private, may accordingly be needed.
>
> (c) in the case particularly of the Northern and Midland areas the question of a dual use of gathering grounds, especially for afforestation or hill sheep farming, and the formulation of rules capable of wide application governing public access.
>
> (d) the facilitation of a piped supply to all farms, market gardens and allotments.
>
> Without expressing a definite opinion, we desire to place on record that evidence has been received showing that certain water companies, or the bodies controlling them, have used their priviledged position as statutory undertakings outside planning control to take action which might have been modified to serve better the national interests. The siting of reservoirs, the compulsory acquisition of some of the finest land in the country, the prohibition of access to areas controlled, and conditions imposed as to supply to areas passed by long distance mains have all been mentioned in evidence. We consider that all water undertakings should be brought under the national planning control, while leaving the supervision of their development functions to the appropriate executive Ministry.
>
> *Way Leaves.*—We recommend that the position with regard to way leaves should be examined and that electricity, gas and water supply undertakings should be placed on a comparable footing and that provision for the requisite rights of compulsory acquisition of land and way leaves should be embodied in

local planning schemes. All questions affecting more than one local planning authority will, under the new legislation, be naturally the concern of the Central Planning Authority.

Sewerage.—The provision of a piped water supply results inevitably in a large per capita increase in the consumption of water, and may render inadequate many local sewerage systems previously both efficient and adequate. A main drainage system is frequently more difficult and more expensive to provide than a main water supply, but is not inevitably necessary. We consider that the provision of an adequate water supply is so important that it should not necessarily be held up because difficulties of disposal of sewage may arise later but consider that the latter problem must be investigated individually in each case.

In discussing industry in country areas the report points out that "reservoirs and associated dams and buildings have introduced variety into otherwise rather dull country. . . . Not a few reservoirs with associated afforestation and other features are numbered among the nation's "beauty spots"—Lake Vyrnwy is an example." Nevertheless, the committee sees "no justification for treating public utility undertakings from other enterprises undertaking constructional development. . . ." and states "that all such undertakings should be subject to national planning control."

The report contemplates the setting up by the government of a Central Planning Authority and that this should be done before the end of the war. Local authorities would still do the local planning but their plans would have to be co-ordinated with those of adjacent areas and fit in with the national plan. Procedure to be followed is also outlined.

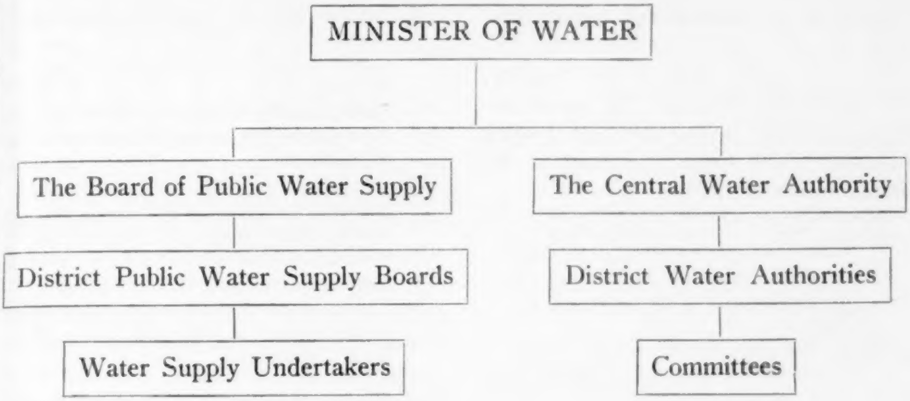
Part IV of the report is a Five-Year Plan for Britain and calls for, among other things, the completion of the comprehensive investigation of electricity, gas and water supplies, as called for in the recommendations, within the first year. It recommends the completion of the program based on said survey or investigation within the five-year period.

A reservation by two members of the committee relative to the Central Planning Authority section of the report, a minority report filed by Professor Dennison, as stated at the beginning of the review, and an appendix concluded the subject matter of the report. The part of Professor Dennison's report probably of most interest to water works men is his statement that *"The suggestions of the majority report for improved public services in rural areas involve costs to the community which have not been fully examined, and are not presented in the report."*

First and Second Reports of the British Waterworks Association on Control of Water Resources

The first report was made in May 1943 to the President and members of the Executive Committee of the British Waterworks Association and covers the subject of Underground Water. The committee seemed to feel that things needing most attention were: (1) change in the law relating to the use of underground water and (2) the inadequacy of the Common Law in connection with contamination of underground water.

The committee points out "that there is no private property in regard to underground percolating water, that is, water not flowing in a defined channel. Every freeholder is entitled to do what he likes with his own land and the general law is that he who owns the surface of the land owns everything thereunder down to the middle of the earth,



including any water which may naturally find its way into that land." It seems, however, that this does not apply to public or private water utilities who have to obtain their power from Parliament or go through Provisional Order procedure, and are therefore subject to restrictions so as to insure that persons injured or likely to be injured as a result of their activities, shall not be damaged. It appears that this has resulted in much unfairness to utilities.

> The Committee considers that it would be more equitable and more to the public interest if property owners were treated in the same way as water undertakers in any projects where the former may wish either to sink wells below a certain depth or extract more than a certain quantity of water from them except for their own agricultural or domestic purposes.

With respect to the pollution of underground water supplies it appears that "the damage has to be done and the precise source of the pollution proved before successful action can be taken." The committee apparently feels that the Common Law is inadequate in connection with the contamination of underground water and urges that legislation be introduced at the earliest possible moment to deal with the problem of underground water pollution.

A summary of the basic recommendations of the second report of the committee, presented March 16, 1944, follows:

(a) That the water resources of the country, from whatever source, should be regarded from a national rather than a local aspect.

(b) The establishment of a Central Water Authority to conserve the water resources of the country and to consider and decide conflicts between various authorities interested in water.

(c) The setting up, in addition to the Central Water Authority, of a Board of Public Water Supply having general jurisdiction over the water supply industry, to whom problems which are exclusively the concern of water supply undertakers should be submitted.

The report also recommends "the appointment of a Minister of Water to be responsible for the conservation and utilization of the water resources of the country in the best interests of the nation."

A diagram showing the control of water resources and supplies as proposed is given above.

As it is not feasible for any central body to control in detail water resources in every part of the country, the report recommends the establishment of district bodies for each district into which the country should be divided, which would be:

(1) A District Water Authority which would be representative of all water interests in the district and be under the supervision of the Central Water Authority.

(2) A District Public Water Supply Board having statutory powers and with the definite duty of the oversight of the public water supply in their respective areas. Members of this Board would be elected by the water undertakers in each district.

Postwar Water Supply Report of Institution of Water Engineers

This report is dated March 2, 1944. It contains twenty conclusions and recommendations but for the sake of brevity only those which appear to the author to be of greatest importance to water works engineers in this country are given.

1. For various reasons, a National Water Grid, analagous to the Electricity Grid, is not only impracticable but also unnecessary.
2. On the other hand, local regional schemes have for certain areas many advantages and should be encouraged.
3. The existing and potential sources of supply, if properly conserved, are ample for the present population and for any likely increase in the future.
5. An excess of compensation water is on occasion turned into rivers to little advantage and might well be used to better purpose.
7. A permanent Statutory Authority, analogous in some respects to the Electricity Commissioners, should be set up, whose sole duty would be to deal with all matters relating to public water supplies.
14. A properly designed regional scheme is, or should be, a permanent solution of the problem of Rural Water Supplies.
16. All who have the right (statutory or otherwise) to abstract water from rivers or underground sources should be obliged to make returns as to quantities abstracted, and submit data to indicate the quantities otherwise available.
18. Consideration should be given to the economic wisdom of allowing pure water, often treated at considerable cost, to be used where that purity is not necessary.
20. There is great need for a research organization to cover all fields of water engineering.

The Rural Water Supply and Sewerage Bill

This bill ordered to be printed by the House of Commons, May 4, 1944 is:

To make provision as to water supplies, sewerage and sewage disposal in rural localities, and to make expenses incurred by rural district councils in connection with water supply, sewerage and sewage disposal general expenses.

The explanatory and financial memorandum attached to the bill states that its purpose is to "authorize the Minister of Health and the Secretary of State for Scotland to make contributions in aid of the provision or the improvement of water supplies and sewerage in rural localities; to extend the duties of local authorities with respect to the supply of water in rural localities; and to make expenses incurred by rural district councils in connection with water supply, sewerage and sewage disposal general expenses."

"Clause 1 authorizes the Minister or Secretary of State to undertake to make, subject to conditions laid down by the Treasury, contributions towards the expenses incurred by a local authority in providing a water supply in a rural locality, whether it is a new supply or an improvement of an existing supply, and in providing sewerage or sewage disposal necessary in con-

sequence of the provision, whether in the past or future, of a piped water supply."

Subsection 2 states that, "An undertaking under this section shall provide for the making of the contribution in the form of a lump sum, payable either as a whole on the completion of the works to be executed or of the transaction to be effected for the purposes of the supply of water or the purposes of sewerage or sewage disposal, as the case may be, or, in the case of the execution of works, in installments on the completion of part of the works."

Again quoting the explanatory and financial memorandum, Subsection 3, "provides for the payment of annual sums for a period of not more than 20 years towards expenses incurred under arrangements made with other bodies for the supply of water or disposal of sewage."

Subsection 4 "gives power to withhold, or reduce, any grants promised if it appears that the carrying out of the work has been unsatisfactory, or there has been default on the part of the authority."

Subsection 5 "provides that the contributions are to be defrayed out of moneys provided by Parliament and are not to exceed, in England and Wales, £15,000,000 in the aggregate. Clause 7 (2) provides that the corresponding amount in Scotland shall be £6,375,000."

Subsection 6 states that local authorities shall be:

(a) the council of any borough or urban or rural district;

(b) the council of a county which is for the time being exercising the functions relating to water supply or sewerage or sewage disposal of any such council as aforesaid by virtue of an agreement under section three hundred and twenty, or an order under section three hundred and twenty-two, of the Public Health Act, 1936, or by virtue of a local act (whether passed before or after the passing of this Act);

(c) a joint board, or joint committee, constituted by or under any act (whether public general or local and whether passed before or after the passing of this Act) for the purposes of the provision of a common water supply or common sewerage or common sewage disposal."

Again the explanatory and financial memorandum states:

"Subsection 7 repeals the Rural Water Supplies Act, 1934, with a saving for undertakings already given. This Act provides for contributions out of moneys provided by Parliament towards the cost of improving water supplies in rural localities up to an aggregate not exceeding £1,000,000 in England and Wales and £137,500 in Scotland. Practically all of the moneys has been already paid in grants or is the subject of undertakings to pay.

Clause 2, which does not apply to Scotland, provides that where an undertaking has been given to any authority, the county council or county councils in whose area the authority lies shall make a contribution towards the expenses of the authority, the amount of the contribution and conditions of payment to be settled by agreement between the county council and the authority, or, in default of agreement, by the Minister.

Clause 3 extends the duty of a local authority (that is, the council of a borough, urban district or rural district —see subsection (2)) to provide a piped supply of water to every rural locality in their district in which there are houses or schools and to take the pipes to points which will enable the houses or schools be connected thereto at a reasonable cost. The provisos to subsection (1) limit the obligation of the authority to doing that which is practicable at a reasonable cost and provide for determination by the Minister of questions which may arise under the subsection. Subsection (2) makes the new obligation part of the obligations imposed by Section III of the Public Health Act, 1936 (in Scot-

land, by the Public Health (Scotland) Act, 1897). Subsection (3) imposes a similar obligation on joint boards already constituted under the Public Health Act, 1875, or under the Public Health Act, 1936. This subsection does not apply to Scotland (Clause 7 (3) (1V)).

Clause 4 amends section 322 of the Public Health Act, 1936, by enabling the Minister, where he has made an order under subsection (2) of that section declaring a council of a county district or a joint board to be in default in connection with the supply of water in, or with the sewerage or the disposal of the sewage of, a rural locality, to transfer the powers of the local authority concerned to himself instead of to the county council. This clause does not apply to Scotland (Clause 7 (4)).

Clause 5 empowers local authorities to give guarantees to statutory water undertakers (which means any company, local authority, board, committee or other person or persons supplying water under any enactment—see subsection (5)) in cases where the aggregate amount of the water rates which would be payable by consumers in a rural locality is not sufficient to enable the consumers to require the undertakers to bring water to the locality, and requires the undertakers, when a local authority gives a sufficient guarantee, to bring water to the locality. This clause does not apply to Scotland (Clause 7 (4)).

Clause 6 makes expenses incurred by a rural district council, whether before or after the passing of the Bill, in connection with sewers or sewage disposal works or a supply of a water, general expenses insofar as they fail to be defrayed out of rates made in respect of periods beginning after the end of March, 1945. This clause does not apply to Scotland (Clause 7 (4)).

The schedule indicates the provisions to be repealed by the bill, and the extent of the repeal.

Agriculture (Miscellaneous Provisions) Bill

This bill is apparently intended to fill the gap left by the Agriculture (Miscellaneous Provisions) Bill of 1940 and the Rural Water Supply and Sewerage Bill reviewed above. It appears that under the Agriculture Act of 1940 that, while provision was made for financial assistance by the government in connection with water supply projects to farms and farm buildings, it did not permit the government grant to be extended so as to assist in securing a domestic water supply for farmhouses and farm cottages. Clause 5 of the current Agriculture (Miscellaneous Provisions) Bill enables a grant to be made for taking farm water supply to a farmhouse or to any cottage or cottages close by. Under this bill, if there were reasonable prospects of a public water supply becoming available under the Rural Water Supply Bill within a reasonable time, no grant would be made. In other words, isolated groups of buildings or farms, which it would now be impossible to serve by a public water supply, could obtain it under this bill.

Water Supply and Sewerage in Northern Ireland

This report on the problems of Water Supply and Sewerage in Northern Ireland is submitted by the Planning Advisory Board of the Government of Northern Ireland and presented by the Minister of Home Affairs to Parliament. The purpose of the report is "to consider and report on the problems of water supply and sewerage and the adequate provision of these facilities in urban and rural areas throughout the Province."

The Water and Sewerage Committee of the Advisory Board recommends dividing Northern Ireland for water and sewerage purposes into four regions, each under an authority consisting of representatives of the urban and rural councils within the region

with each having a competent technical staff. These authorities would have control over all sources of water supply and of all trunk mains, and be responsible for the delivery of water in bulk into the service reservoirs or the distribution systems of existing local authorities, which, however, would continue to be responsible for the distribution of water supplies within their areas.

Regional authorities should be empowered to abandon existing works which they consider unsuitable and can construct new works or supply the area from other works.

Sewage disposal works and outfall sewers should be taken over and maintained by the regional authority, except in the cases of Belfast and Londonderry, where the existing works and staff are adequate. Sewerage systems should remain under the control of the existing sanitary authority which should be required to pay to the regional authority its proper proportion of the annual cost of the maintenance of outfall sewers and sewage disposal works.

The regional authorities should investigate the pollution of streams and make recommendations as to improvements.

In the event of the local authority failing to carry out its duties efficiently, the Ministry of Home Affairs should have the power on representations from the regional authority or from the ratepayers of the town or of the area concerned, to transfer the distribution system to the regional authority.

Existing distribution systems could be used by the regional authority for supplying other areas where this is the most economical course to follow and does not prejudice the interests of the local authority.

The expenses of the regional authority would be met by charging an annual lump sum to each rural and urban authority, which sum, except in the case of increased facilities, should be approximately equivalent to the amount raised through the existing local rates to cover the expenditure taken over by the regional authority.

The committee is of the opinion that areas which in the future obtain supplies from sources already existing and belonging to other authorities should bear not only the cost of the extra piping but should also make a contribution to the original capital cost of the source. To safeguard local interests the committee feels that local authority should be given the right to appeal to the Ministry of Home Affairs in any event that it may feel aggrieved by the action of the regional authority.

The committee recommends the setting up of a Central Co-ordinating Committee consisting of two representatives of each regional water and sewerage authority together with additional independent representatives appointed by the government. The functions of the Central Committee would be to act as a clearing house and thus insure uniformity of policy among the various regional authorities. The committee would have a technical sub-committee consisting of the engineers of the regional authorities, and the Central Committee should, through this technical sub-committee, maintain a reference library and a laboratory. Applications for loans and grants should be submitted by the regional authorities through the Central Committee to the Ministry of Home Affairs. It was not felt that the Central Co-ordinating Committee should have statutory authority.

An interesting statement is that the regional authorities should, in many cases, take over the existing gathering grounds, reservoirs, trunk lines, way leaves, pumping and filtration plants, without payment of compensation beyond the transferance of outstanding debts. This would apply to water undertakings by local authorities.

The report states that "We are of opinion that every effort should be made within a period of years to provide, as a minimum, a piped water supply to communities of approximately 250 persons resident within about a quarter mile radius, unless it is found in any particular case that the cost is prohibitive."

A National Water Policy

This paper was submitted by the government to Parliament in April 1944. It "is concerned with ways and means of insuring that all reasonable needs for water can in the future be met—and that they can be met speedily and without avoidable waste, either of water itself or of labor, materials or money." In the introductory remarks statements are made to the effect that there is ample water in the country for all requirements and that, therefore, the problem is not one of total resources but of organization and distribution. Defects in the present water supply system are briefly outlined herewith:

Central and Local Organization. The responsibility of the Minister of Health and his powers under water supply are both somewhat vague and ill-defined. Where local authorities operate under general powers of the General Health Acts the Minister's powers are rather extensive. The Minister does not, however, have power to authorize the taking of water compulsorily from a river or stream. Twenty per cent of the water undertakers are statutory companies deriving their power from Parliament which itself has no machinery for insuring that the powers are properly exercised. In such cases, except where local acts confer specific powers on the Minister, he has no adequate power to supervise. Also, while it is a general obligation under the Public Health Acts for local authority to review from time to time its sufficiency of water supplies in that area, this obligation does not require them to make sure that the water mains are taken to such points as will enable a piped supply to be carried into the houses. If they themselves are not water undertakers they have no adequate power to take the necessary corrective steps.

Multiplicity of Water Undertakers. There are over a thousand water undertakers in England and Wales. Twenty-six of these supply between them 50 per cent of the total population, and 123 supply 75 per cent. Serious failure of supply in times of difficulty usually arises in small undertakings which lack the financial resources to secure themselves against the risk of drought.

Information and Surveys. Much more detailed information is still required about the behavior of both surface and underground sources over a long period and the use which is made of them.

Protection of Resources. There is need in the public interest for special measures to prevent misuse and waste of underground sources of supply and there is need for some further tightening up of provisions against pollution.

Water for Industry, Agriculture, etc. At present the obligation of public

water undertakers does not extend to supplying water for non-domestic use. This is serious from the standpoint of agriculture.

Domestic Supplies in Rural Areas. Despite the improvement in the past decade, nearly 30 per cent of the people living in rural districts are still not reached by water mains.

Water Charges. In some cases water charges should be leveled over wider areas by the amalgamation of undertakings which would secure greater all-round efficiency and economy. There is also need for a uniform procedure for the revision of charges to replace the present welter of varying methods by which consumers or undertakers can seek alterations.

General. The rise of standards of living and urbanization make necessary a thorough overhaul of the present water supply system.

In order to carry out the objects of its policy to make the best and most economical use of the country's water resources, the government proposes the following:

(a) The Health Ministers, whose powers are at present vague and ill-defined, to be given the statutory duty of promoting the provision of adequate water supplies and the conservation of water resources.

(b) The central planning of water policy to be the function of the Health Ministers. The policy to be based on information, systematically collected and assessed, regarding water resources and needs, and is to be applied by a simplified system of ministerial orders. Orders by reason of their intrinsic importance or because of their effect on the interests of the general public or of individuals, are subject to be reviewed by Parliament.

(c) The Central Advisory Water Committee for England and Wales to be reconstituted as a statutory body, which would, of its own volition, give advice on general principles affecting water administration to the various departments of the government. A somewhat similar committee would be set up for Scotland.

(d) The work of the Inland Water Survey, to secure the scientific assessment of yield, quality and behavior of water resources, both surface and underground, and to collect and make records generally available, to be pressed.

(e) Surveys of bulk needs of large areas to be continued to be carried out in England and Wales by the Regional Advisory Water Committees, which would be reconstituted and empowered to require information and statistics. (There are nine of these committees covering the more densely-populated districts in the country. In areas of more scattered population where Regional Committees are not required the government considers that county councils can often play a similar part and co-operate with district councils and other water undertakers in reviewing the needs and resources of the area.)

(f) Surveys of the efficiency of water supply services to be carried out regularly by the expert staff of the Ministry of Health which will need to be strengthened for the purpose.

(g) Greater use should be made of the resources of government departments, particularly the Ministries of Agriculture and Fisheries and of Town and Country Planning—in building up information relating to water supplies and needs. Close touch should be maintained with town and country planning policy.

(h) The powers and duties of local authorities and general framework of water undertakers are to be retained, but the default powers of Minister of Health shall be strengthened to the extent of requiring a statutory water company to carry out any essential work which he is satisfied that they can reasonably be required to carry out. In case of non-compliance by the company, to make an order transferring the undertaking to a local authority or

other water undertaker, if that is necessary to insure adequate supplies. Amalgamations of undertakings are to be encouraged, and if necessary enforced, to secure efficiency and economy.

(j) The giving of bulk supplies by one undertaker to another to be, if necessary, enforced.

(k) Special steps are to be taken to protect water resources against misuse, waste and pollution. (This goes back to the briefly mentioned proposition that private owners of land have unfettered rights for all water under their land which does not flow into defined channels.) The Minister to be empowered to prohibit the abstraction of water within an area without the consent of a Minister except where the private individual uses water for his own domestic purposes. Mining undertakings to be obliged to take such measures as are agreed by the Minister of Health and the Minister of Fuel and Power to be necessary and practicable for conserving water in the strata without interfering with the winning of the mineral. The government also proposes to make it an offense to allow underground water to run to waste from borings or to pollute it. Finally, the Minister to be empowered to obtain from any company or person any necessary returns of the quantity and quality of water (other than water taken by a private individual for his own domestic use) abstracted from underground.

(l) Industry and agriculture would have the right to require being supplied with water on reasonable terms and conditions by water undertakers, provided the same could be done without endangering the amount of domestic supply.

(m) The undertakers to be enabled, subject to proper safeguards, to take water from rivers and streams on reasonable terms and conditions and to acquire land compulsorily.

(n) The Health Ministers to have powers to require information and statistics from all users of water and all sinkers of wells and boreholes.

(o) The government proposes to submit to Parliament legislation providing for the necessary new powers outlined aboved, including provisions on the lines of the Water Undertakings Bill of 1943. (Not passed.)

(p) "In advance of the general legislation, a bill to be presented to Parliament at an early date to provide Exchequer grants totalling £15,-000,000 for England and Wales, and £6,375,000 for Scotland, for extension of piped water supplies and sewerage in rural areas. In England and Wales the bill will abolish special expenses for water and sewerage, so that costs will fall on the district instead of the parish, and will provide for contributions by county councils to grant-aided schemes. The scheme for securing piped supplies for agricultural land to be extended to cover farm houses and cottages."

Labor Party's Postwar Water Policy

This is given in the Appendixes of Volume XXVI, Number 198, February 1944, of the Journal of the British Waterworks Association. A statement of the policy starts out by saying that, "Pure water is a vital necessity, a plentiful supply of which must be made available to every house, farm and industry." Reference is made to the report made by the Scott Committee where the view is expressed that lack of water supply and sewerage is a contributory factor in the drift from the countryside to the towns. The recommendation is made that all water undertakings be placed under national planning control. The labor statement also agrees to the adequacy of water resources but says that, "Our resources are adequate for this purpose, but owing to the absence of effective planning there are many areas where supplies are inadequate in quantity or quality, and often both."

Under the heading "Responsibility for the Supply of Water" the necessity of reorganizing the units of water supply on a far wider basis than at present is pointed out and the statement made that the spread of charges over wide areas is justifiable on public health grounds alone.

The Labor party paper states that "A survey of all underground and overground sources is an essential preliminary to an appropriate allocation of supplies." It also states that "Such a survey will require the setting up of a Water Commission to plan and administer the water industry and to undertake the necessary technical and operative work. Power should be given to the Water Commission to demand the necessary information about all sources of supply."

The paper calls attention to the necessity of the closest possible contact between the supply of water and the provision for disposing of sewerage. Under the heading "Lack of National Control" it is pointed out that measures of a more comprehensive character for an adequate study of both surface and underground water supplies are necessary.

In discussing "Regional Committees" a statement is made, "It is now clear that regional organization is bound to be ineffective unless there is a National Water Commission possessing full powers over the nation's water resources."

The necessity of providing necessary water for the canal expansion program in Britain in connection with the reorganization of the water system is mentioned.

Under the heading "Government Departments Concerned in Water Supplies" the following recommendation is made which would seem to be the crux of the whole policy:

> We therefore propose that the control of water supplies, land and main drainage, nontidal rivers, and the utilization of water resources in Great Britain should be vested in a National Water Commission, and that local water supply should be undertaken by publicly-owned and controlled water boards functioning over wide areas.

Editorial Note

The Association is indebted to Mr. Shaw for his adequate and thoroughly objective summary of the various British documents relating to water resources and supply. It is essential that this American association know what our British contemporaries are doing.

With similar objectivity, readers of this JOURNAL should consider what parallels, if any, exist in North America in the problems of water resources, of surface water pollution, of ground water depletion, of water works management. If such parallel problems exist, how should their solution be planned—within state lines, nationally, on a continental basis?

It will be helpful to any reader to be reminded that England, Scotland, Wales and Northern Ireland (the area covered by the review) have in the aggregate an area less than either Arizona, California, Colorado, Montana, Nevada, New Mexico, Oregon, Texas or Wyoming. Illinois and Indiana together almost equal Great Britain in area. New York and Pennsylvania together exceed Great Britain's area.

In density of population per square mile, Massachusetts, New Jersey and

Rhode Island as individual states exceed (not greatly) the population density of Great Britain as a whole.

Britain therefore has an area less than that of California, Illinois and Indiana or New York and Pennsylvania, with as many people per square mile as there are in Massachusetts.

The general hydrological conditions in Great Britain vary less than is the difference between Oregon and Arizona, between Texas and Montana, between California and New York. Similarly, problems of water supply and control must vary as here widely.

It would appear that the solution of these problems should be, in the United States, approached from the level and the viewpoint of the state governments, rather than at a federal level. To the Editor of this JOURNAL every good reason that Great Britain conceives to support national water control calls in the United States for similar organization at state levels, with the fullest reasonable implementation through the mechanism of interstate compacts whenever problems need to be attacked on a regional or river-basin level.

Relation of Runoff and Water Quality to Land and Forest Use in Cedar River Watershed

By Bror L. Grondal

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Presented on May 12, 1944, at the Pacific Northwest Section Meeting, Olympia, Wash.

THE major portion of the Cedar River watershed of the city of Seattle lies within the boundaries of the Snoqualmie National Forest, and includes the upper drainage basin of the Cedar River with its minor tributaries. It covers an area of approximately 91,400 acres, and timber owners have given the city title to nearly 64,000 acres of this land, although much of the timber is still in private ownership.

Since the city asserted its right to the water just before the turn of the century, logging has continued with virtually no interruption, and hydroelectric plants, sawmills and other manufacturing plants have operated on the watershed. At the present time, however, no lumber is milled on the watershed. In 1906, the city granted a right-of-way to the Chicago, Milwaukee and Puget Sound Railway, virtually paralleling the banks of the Cedar River for 10 mi. within the watershed, after a report prepared by a board of prominent engineers gave assurance to the public that no pollution hazards would be introduced by the operation of the railroad in such close proximity to the river.

During the entire history of the watershed, it has been the subject of political discussion. In 1929, litigation over a contract, held by a lumber company which was logging in the watershed, was initiated by the city, in an avowed attempt to end all logging in the area ostensibly to "protect the water supply." As the final verdict indicated that the lumber company had observed all contractual obligations, this attempt to stop the logging failed, but the lumber company became bankrupt in 1940, and since that time logging in the watershed has been restricted to the activities of two logging operators working on a relatively restricted basis.

Recently, as a prelude to a political campaign, a strenuous attempt was made to inject the subject of "logging on the watershed" as an issue—one group in the city council asserting that such logging introduced a serious pollution hazard that threatened the health and well-being of every resident of Seattle; while another group contended that the prohibition of logging would accomplish no useful purpose, but would merely reduce water department revenues.

Due to the controversy within the council, and largely upon the insistence of one businessman member, the city council decided to appoint a commission of reputable and unbiased experts to make a careful study of the watershed, with the primary object of deciding future policies with respect to logging. This commission

FIG. 1. Logged-off Area—Seed Trees Left in a Block on Rocky Ridge—Taylor Creek Area of Cedar River Watershed

FIG. 2. Logging in the Cedar River Watershed—Elevation, 3,000 ft.—Sanitary Portable Closet Near Automobile, Provided for Loggers to Prevent Pollution

was duly appointed, selections being made from lists prepared by the Secretary of Agriculture of the United States, the Secretary of the Interior and the Surgeon General of the U.S. Public Health Service. This resulted in the appointment of Abel Wolman, Professor of Sanitary Engineering at Johns Hopkins University, and Carl Green, of John Cunningham and Associates, Portland, Oregon. The author was appointed as the third member. This commission completed its field studies in January 1944, and in a report which was submitted to the mayor and council in March, recommended a continuation of logging on the watershed on a controlled sustained-yield basis.

Briefly, this conclusion was based on the following considerations:

(1) Due to the porosity of the soil in this watershed, there is virtually no surface runoff, and hence erosion is not accelerated by the removal of the forest cover (Fig. 1).

(2) Storage of snow is somewhat increased when the larger trees of the virgin forest are replaced by young growing stock.

(3) The quality of the water is not adversely affected by the removal of the forest cover, as the lack of erosion prevents any increase of turbidity in the streams in the watershed after the timber has been cut.

(4) Adequate control measures, already in practical operation, have conclusively demonstrated that pollution due to logging operations in the watershed can be prevented in a completely satisfactory manner (Fig. 2).

(5) All surface waters should be chlorinated or otherwise treated, regardless of the seeming absence of hazards, and there are already definite hazards, such as (a) a railroad paralleling Cedar River (Fig. 3), (b) employees resident upon the watershed, (c) a manufacturing plant and small town, and (e) a public highway. These are potential, if not actual, sources of pollution already existent upon the watershed. The very minor hazards introduced by logging operations, being controllable, could be regarded as negligible.

(6) Revenue from logging is, and will be, substantial, and can in the future pay a large part of the administrative costs of the water department.

(7) As almost all of the virgin timber remaining in the watershed is either privately owned or is in a national forest and is merchantable, prohibition of logging in the watershed area would compel the purchase of the privately-owned timber at a cost of approximately $2,000,000, plus annual charges based upon a capitalized value of $2,700,000, if timber sales were not permitted in the national forest. As no benefits in the form of additional or purer water supplies would accrue to the city, such large expenditures can not be regarded as justifiable.

(8) The timber in the watershed is economically important to the region, and when the logs are delivered to manufacturing plants, such as pulp and paper mills, plywood factories and sawmills, they will furnish employment, directly and indirectly, to several thousand persons for an indefinite period.

(9) Forest conditions in the watershed can be improved greatly by the practice of forestry (Fig. 4). The successful re-stocking of a considerable portion of the watershed that has already been logged demonstrates this fact.

(10) "Ostrich-like" confidence in a "closed" watershed, instead of controlled intelligent use, will create a

FIG. 3. *Foreground*—"Milwaukee" Railroad Track, With Cedar River Immediately Adjacent but Obscured by Trees—All of Reforestation Result of Tree-Planting Program

FIG. 4. Logging in Upper Cedar River Areas—When logging debris forms humus, site conditions will improve and second crop of timber will grow at faster rate than virgin timber.

false sense of security that will not facilitate the application of improvements in water treatment methods that existing hazards demand.

From the intake at Landsberg to Cedar Falls, the drainage area, exclusive of that above Cedar Falls, is described as the "lower watershed." A rather large tributary of the river, known as Taylor Creek, joins Cedar River at a point approximately halfway between the intake and Cedar Falls. This creek has a drainage basin of about 20 sections of mountainous country, and although extensive areas have been logged in this basin, the water of Taylor Creek is very low in turbidity except for very brief periods when climatic conditions are temporarily very severe. A surprisingly large proportion of the precipitation in the watershed comes to the river in the form of seepage, although several creeks empty directly into the river. The effluent from two creeks, one from the town of Taylor (Hotel Creek) and one from Walsh Lake (Rock Creek), both within the watershed and which carry polluted water, have been diverted from Cedar River, as shown in Fig. 5.

During the period from 1895 to about 1925, virtually all of the timber in the lower watershed, excepting the timber in the upper drainage basin of Taylor Creek, was cut.

The so-called "upper" watershed of about 61,000 acres includes Cedar

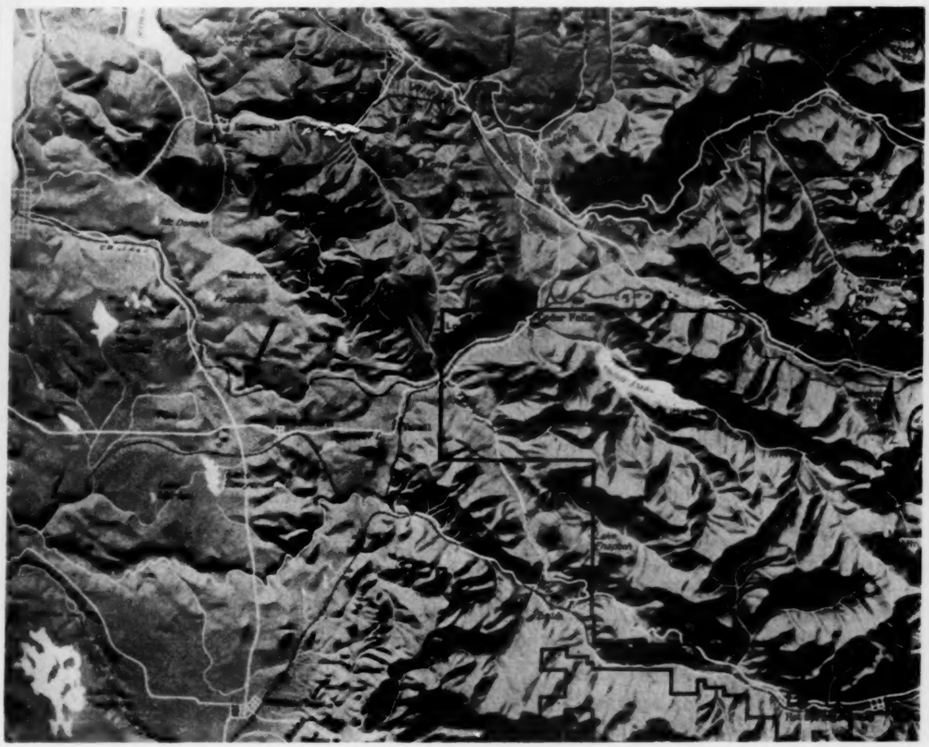

Fig. 5. Relief Map Showing Cedar River Watershed—*Arrow,* Landsberg Intake

Lake, the river above this point, and Rex River, which drains into Cedar Lake.

During the entire period over which the city of Seattle has derived its water supply from the Cedar River watershed, logging has been conducted in the area, usually on an extensive scale. Forest fires have at times affected the water to a minor degree, but no serious and deleterious influences have stemmed from logging. Records of the water department and public health agencies indicate that the water that is supplied to the city from the Cedar River watershed is of exceptionally high quality, and that control measures now employed as a precautionary measure, although regarded by the commission as in some respects inadequate, have in the past been effective. Logging of the timber on the watershed on a sustained annual yield basis, using advanced silvicultural methods, has been recommended by the commission as a safe rational conservation measure.

Editorial Note

In a report made by the Cedar River Watershed Commission, Feb. 15, 1944, the following material appears to be of general importance:

The Seattle municipal authorities might well give careful consideration to a change in philosophy with respect to the watershed. Such extensive recreational areas exist elsewhere in the Puget Sound area that there need be no reasonable demand for the use of controlled recreational areas within the watershed, but controlled logging practices and *controlled* but reasonable access to the public, as, for example, in the present operations of the hydro-electric power plant, manufacturing plants, mines, and public highways, should not cause hysteria.

Such procedures of conscious control appear to the Commission to have less risk to the consumer than the "ostrich-like" confidence in a closed watershed, supported by statutes and ordinances, which do not provide the equivalent of protection.

Intelligent, conscious controlled use of the watershed, for economic and even recreational purposes, bolstered by adequate treatment processes, perhaps later including filtration, would result in a higher factor of safety to the consumer than is afforded by the present faith in a non-existent situation.

Successful management of the watershed can only rest, however, upon a carefully defined policy and program which will place the control upon a permanent administrative base. Changing municipal administrations must be prevented from modifying the control procedures for one expediency or another as time goes on. To accomplish this objective the city authorities should develop with the utmost care a statement of policy and program which could be translated legally into an effective administrative procedure, not easily disturbed in subsequent years. The purpose of this particular recommendation is to emphasize the fact that the complicated negotiations by the various levels of government and private agencies essential for the crystallization of a watershed control plan should have some guarantee of permanence and of stability beyond that normally experienced in such negotiations in the past. If such a plan of action is consummated, the people of Seattle may look forward to an intelligent and logical program for many decades, which would preserve the water supply values of the Cedar River watershed to the utmost, and, at the same time would make maximum beneficial use of the fine resources which now cover the shed. It is the unanimous conviction of the Watershed Commission that there are no inconsistencies in a policy and program which results in protecting the water supply values simultaneously with the conservation and use of the timber resources of the Cedar River watershed.

Relation of Runoff and Water Quality to Land and Forest Use in the Green River Watershed

By W. A. Kunigk

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Presented on May 12, 1944, at the Pacific Northwest Section Meeting, Olympia, Wash.

SINCE the early part of 1913 the principal source of Tacoma's water supply has been Green River. The intake of the Green River gravity system is located about 28 mi. easterly from Tacoma at an elevation of 908.8 ft. above sea-level in the foot-hills of the Cascade Mountains. The gravity supply system has a capacity of about 85 sec.ft. or approximately 55 mgd. When this gravity system was completed, the intake proper and the three tunnels and pipeline immediately below the headworks leading to the Green River bridge one-half mile below the intake were designed for a total capacity of 130 sec.ft. or approximately 84 mgd. It was originally planned to build ultimately two pipelines from the Green River crossing to Tacoma, each with a capacity of 42 mgd. but only one pipeline has been built. In the reconstruction of the original wood stave pipeline, which has been under way since 1924, larger diameter of pipe has been substituted with the result that the capacity of the gravity system was increased from 42 to 55 mgd. Over 75 per cent of the old wooden pipeline has been rebuilt to date. This system supplies at the present 142,000 people inside the city limits and approximately 10,000 consumers outside the city limits, or a total population of 152,000.

The city also maintains an auxiliary well supply system inside the city limits with a capacity of 35 mgd. The wells are used when there are interferences on the gravity system or when peak demands during the sprinkling season exceed the capacity of the gravity pipeline. Interferences on the gravity system are often caused by necessary repair work or may be due to turbid water conditions in the river. Whenever turbidities greater than 10 ppm. appear, the water is bypassed at McMillin Reservoir into the Puyallup River when the turbidity reaches that point.

The maximum daily peak demand on the distribution system to date was on July 14, 1941, with a total consumption of 77.85 mil.gal. On the same date, peak demand rates for the duration of 2 hr. each during morning and evening were over 95 mgd. These maximum peak demands are equalized by the storage in the 110-mil.gal. reservoir at McMillin, 26.7 mi. below the intake, and the two pipelines leading from there to the city. The capacity of the two pipelines from McMillin Reservoir to the city is practically twice that of the single pipeline from the intake to the reservoir.

The Green River watershed covers an area of some 231 sq.mi., extending from the city's intake at an elevation

of 908.8 ft. for a distance of approximately 25 mi. easterly to the top of the Cascade range. Roughly, the north and south width of this area is from 8 to 10 mi. Several of the highest mountain peaks in the range, which forms the north, east, and south boundary of the Green River watershed basin, exceed 5,000 ft. in elevation. With the exception of some eight or nine thousand acres of comparatively level land near Lester and along the river banks in the vicinity of Maywood, Eagle Gorge and in the drainage basin of the North Fork, the whole area is very mountainous and rugged, rising quite abruptly from the narrow river valley to the top of the surrounding mountain range.

As already stated, the capacity of the single pipeline from the intake to McMillin Reservoir is now 85 sec.ft. Based on a few isolated measurements, the original designers of the Green River gravity system had, no doubt, assumed that the river flow would never drop below 130 sec.ft. Except during the summer of 1932 when the low river flow at the intake was 154 sec.ft., the minimum runoff at this point during the last twelve-year period, Oct. 1, 1931 to Oct. 1, 1943, has always been below the original estimate. Whether this was due to the fact that only a few isolated river flow measurements were originally available from which over-optimistic deductions were made, or if some of this apparent decrease in the low water runoff was due to the change of the forest cover caused by too rapid a rate of logging, or to a general change in precipitation, or was due to other causes, the author does not venture to guess. The designers may also have had in mind a storage development to take care of these low-water periods.

About two-thirds of the Green River watershed area, comprising some 150,000 acres, is covered with second growth timber of varying age classes, generally well stocked. The timber consists mainly of Douglas fir, pine, spruce, hemlock and some cedar. Logging operations have been carried on in the watershed for over 40 years. During the earlier logging operations, several areas were also denuded by forest fires.

Artificial reforestation has not been resorted to by any of the timber owners. Nor does artificial planting seem to be necessary because practially the entire cut-over and burnt-over areas show a healthy growth of young trees. In more recent years proper forest management has accomplished a great deal in protecting the second and virgin growth timber against fires. A number of lookout towers have been erected on the high peaks surrounding the watershed basin and patrol roads, telephone lines and fire breaks have been constructed, all of which are of great help in keeping the forest fire hazard down to a minimum.

Prior to 1937 only about two-thirds of the Green River watershed area was within the Snoqualmie National Forest. By the so-called Boundary Extension Act, adopted Aug. 21, 1937, the entire watershed area may ultimately be brought under the control of the Snoqualmie National Forest administration. This can be accomplished by outright purchase of lands by the federal government or by land exchange for lands that the U.S. Forest Department owns outside of the forest reserve.

Approximately 45,000 acres of the total watershed area is now owned by the National Forest Reserve. Over 40,000 acres are claimed by the Northern Pacific Railway Co. under the

original land grant, and about 18,500 acres are owned by the Weyerhaeuser Timber Co. The rest of the land is held by the state of Washington, King County and some one hundred private ownerships.

At the time the gravity system was first placed in service during 1913, logging and sawmill operations were carried on on a large scale and had then been under way for a number of years. The total population in the watershed at that time was somewhere between 1,800 and 2,000. The sanitary problem in connection with the many sawmill camps and isolated crews working in the woods in widely scattered places presented a real problem in those days. Fortunately, except for one small tie mill, sawmill operations have now stopped entirely and logging has been reduced to a point where the total population in the watershed now varies from about 250 to 350. This figure includes some 150 employees of the Northern Pacific Railway Co., some forest service men, a few ranchers and several small crews usually working on power and telephone lines.

The Northern Pacific railroad main line extends through the full length of the watershed from the intake to the Stampede Pass. While the presence of these people and the railroad presents a sanitary problem that must be closely controlled, it is not a serious one, and is not giving the city any appreciable trouble. Much has been accomplished in this respect by educational methods, instructing the watershed residents and miscellaneous crews to comply with the state sanitary rules and regulations. The few fishermen and hunters who insist on going into the watershed during the summer and fall months are more of a menace to the water supply than the regular residents living in this area.

N. M. Adams, the city's Watershed Inspector, makes daily trips into the watershed and checks the sanitary conditions at each of the small communities about once a week. He also samples the water above and below all these small settlements and takes samples above and below the city's intake and chlorination plant. He therefore has before him a complete cross-section of the sanitary quality of the raw water as well as the treated water. Whenever samples show contamination, he is in an excellent position to trace the locality where it originates.

The most serious problem the city is facing is that of the many small

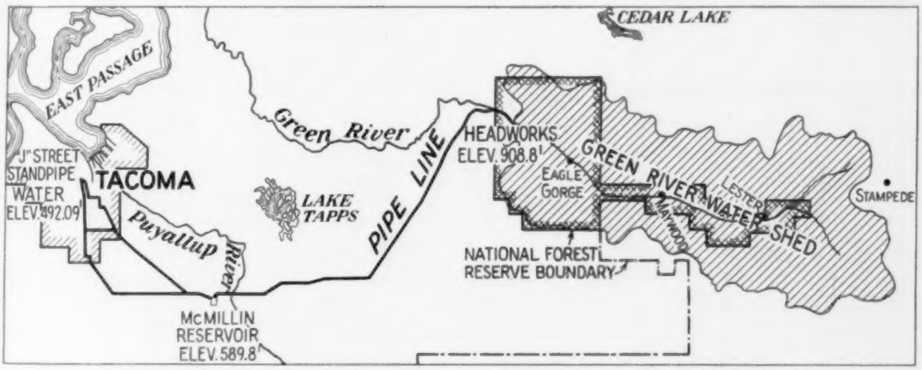

Fig. 1. Green River Watershed and Gravity Pipeline System

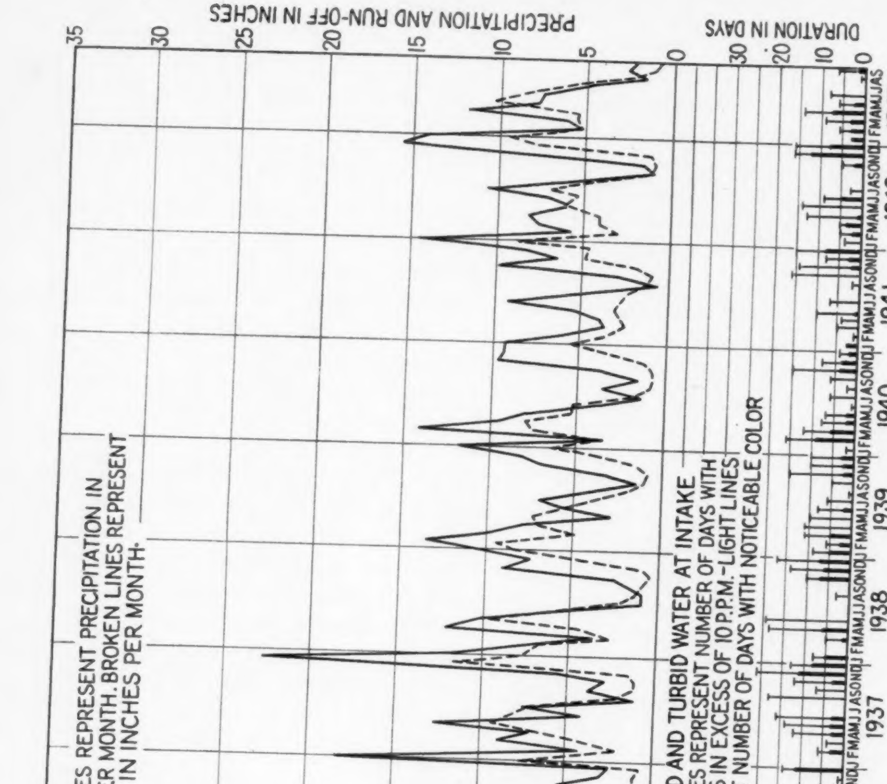

FIG. 2. Cumulative Precipitation and Runoff in Green River Watershed

timber owners who carry on their logging operations without due regard to the effect that their operations may have on the quality of Tacoma's water supply. Where large areas have been denuded of the forest cover, surface soil erosion and consequent turbidities have been caused, which have on many occasions made the water supply unfit for use for days or weeks at a time.

Some very interesting observations have been made by the water department in studying the relation between precipitation and runoff with particular reference to minimum flow records and water quality.

Figure 1 shows the general map of the Green River watershed and gravity pipeline system.

Figure 2 shows graphs of the precipitation and runoff for corresponding periods for the time from Oct. 1, 1931 to October 1, 1943. On the same diagram are also indicated the number of days per month the water showed noticeable color and the number of days per month when turbidities at the intake have been 10 ppm. or higher. Whenever water turbidities higher than 10 ppm. show up at McMillin Reservoir, the water is wasted at that point and a supply is provided from storage supplemented by the South Tacoma well system.

Figure 3 shows graphs of cumulative precipitation and runoff for the same period covered by Fig. 2.

Table 1 shows the basic figures of precipitation and runoff from which Fig. 2 was prepared.

Tables 2 and 3 show the cumulative figures for precipitation and runoff from which Fig. 3 was prepared.

Table 4 shows miscellaneous runoff and precipitation figures.

Tacoma diverts now, roughly, only about 8 per cent of the average annual

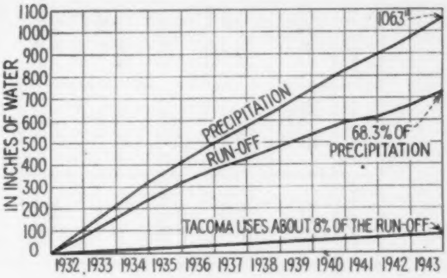

Fig. 3. Precipitation and Runoff Chart for Green River Watershed

runoff at the intake. In other words, less than 5 in. of runoff is required to furnish 85 sec.ft. of water at the intake.

The highest precipitation shows during the water year 1932–33 indicating 110.93 in., while the corresponding runoff was 84.51 in. or 76.2 per cent. The heaviest runoff, as well as the highest percentage of rainfall represented in the runoff, occurred during 1933–34 when the precipitation was 106.15 in. and the runoff 90.37 in., which indicates the extreme high of 85 per cent of the precipitation. The lowest precipitation was recorded during 1940–41, namely 74.22 in., with a runoff of only 30 in. or 40.4 per cent.

It is interesting to note that during 1933–34 when the greatest runoff was recorded, there also occurred the lowest monthly runoff at the intake, which was 0.58 in. during August 1934. During several days of the same month the river flow was down to 81 sec.ft., while during the extremely dry year of 1940–41, the lowest monthly runoff was 0.72 in. when the river flow never fell below 110 sec.ft. Intermittent readings that have been available on a number of occasions from Lester, about 18 mi. above the intake, indicate that here the precipitation is usually from 30 to 50 per cent lower than at the intake, contrary to the commonly

TABLE 1

Precipitation and Runoff in Inches at Tacoma's Green River Gravity System Intake

Month	1931–32	1932–33	1933–34	1934–35	1935–36	1936–37	1937–38	1938–39	1939–40	1940–41	1941–42	1942–43
OCTOBER												
Precipitation	11.50	11.81	10.96	15.62	6.59	2.90	5.62	9.00	6.80	9.73	6.36	8.25
Runoff	3.26	2.87	8.04	5.66	0.80	0.80	1.35	0.83	1.46	1.12	4.80	1.13
NOVEMBER												
Precipitation	10.39	19.02	10.75	15.95	6.24	2.40	22.61	7.37	8.00	9.30	8.30	15.93
Runoff	5.79	18.19	8.97	8.66	1.87	0.61	12.94	4.06	3.29	3.53	4.72	7.69
DECEMBER												
Precipitation	10.56	12.55	33.96	11.50	8.98	19.09	12.19	10.20	11.97	9.24	14.37	13.83
Runoff	4.91	8.64	30.90	8.72	3.19	7.55	8.91	7.99	6.35	5.31	8.78	9.54
JANUARY												
Precipitation	10.54	14.33	15.97	13.44	15.74	4.22	7.85	13.56	3.06	5.78	6.10	5.24
Runoff	8.34	11.99	16.37	13.14	10.18	1.97	8.00	9.64	3.54	3.65	2.89	5.28
FEBRUARY												
Precipitation	14.82	7.38	3.29	6.41	9.02	8.97	3.54	9.76	14.37	3.59	7.62	6.05
Runoff	8.64	2.45	5.14	6.21	3.11	3.74	2.61	4.78	7.21	2.36	4.13	5.60
MARCH												
Precipitation	21.16	13.30	10.56	9.56	7.69	7.13	12.01	7.89	9.43	4.09	7.47	12.15
Runoff	14.76	6.24	9.27	5.65	8.19	7.36	4.97	7.04	7.57	2.59	4.16	5.47
APRIL												
Precipitation	8.88	4.21	4.86	4.14	3.31	12.85	10.12	2.86	7.84	5.36	5.79	7.75
Runoff	10.10	7.73	5.32	5.08	9.58	9.22	10.34	7.33	5.24	3.04	6.00	10.44
MAY												
Precipitation	4.50	7.78	6.65	1.34	9.57	4.05	6.02	5.49	3.70	9.26	6.91	7.58
Runoff	8.19	9.73	2.93	6.26	11.10	8.92	7.99	5.84	5.25	2.64	5.32	7.51
JUNE												
Precipitation	2.05	4.42	1.12	4.76	7.30	7.55	0.89	7.15	1.05	4.67	10.67	4.82
Runoff	5.37	10.33	1.28	3.75	5.30	7.23	2.52	4.05	1.42	2.21	7.41	5.54
JULY												
Precipitation	6.72	1.72	1.74	2.75	2.93	1.07	0.81	3.93	3.51	0.44	4.45	1.42
Runoff	2.01	3.47	0.85	1.67	1.57	2.26	1.01	1.68	0.84	1.03	2.31	2.20
AUGUST												
Precipitation	6.90	3.80	1.16	1.68	1.29	3.96	1.75	1.43	1.49	2.91	0.80	2.62
Runoff	1.10	0.98	0.58	0.97	0.78	1.11	0.67	0.82	0.62	0.72	1.07	0.98
SEPTEMBER												
Precipitation	2.03	10.61	5.13	2.95	5.46	2.91	2.06	3.20	3.66	9.85	1.65	2.11
Runoff	1.01	1.89	0.72	0.66	0.77	0.85	0.48	0.73	0.57	1.80	0.66	0.70

Note: Average ratio of runoff to precipitation for this entire period = 68.3%.

TABLE 2

Cumulative Precipitation in Inches at the Green River Intake of Tacoma's Gravity Water Supply

Month	1931–32	1932–33	1933–34	1934–35	1935–36	1936–37	1937–38	1938–39	1939–40	1940–41	1941–42	1942–43
October	11.50	121.86	231.94	342.75	423.82	504.25	584.07	672.92	752.56	830.37	901.22	983.60
November	21.89	140.88	242.69	354.25	430.06	506.65	606.68	680.29	760.56	839.67	909.52	999.53
December	32.45	153.43	276.65	370.20	439.04	525.74	618.87	690.49	772.53	848.91	923.89	1013.36
January	42.99	167.76	292.62	383.64	454.78	529.96	626.72	704.05	775.59	854.69	929.99	1018.60
February	57.81	175.14	295.91	390.05	463.80	538.93	630.26	713.81	789.96	858.28	937.61	1024.65
March	78.97	188.44	306.47	399.61	471.49	546.06	642.27	721.70	799.39	862.37	945.08	1036.80
April	87.85	192.65	311.33	403.75	474.80	558.91	652.39	724.56	807.23	867.73	950.87	1044.55
May	92.35	200.43	317.98	405.09	484.37	562.96	658.41	730.05	810.93	876.99	957.78	1052.13
June	94.40	204.85	319.10	409.85	491.67	570.51	659.30	737.20	811.98	881.66	968.45	1056.95
July	101.12	206.57	320.84	412.60	494.60	571.58	660.11	741.13	815.49	882.10	972.90	1058.37
August	108.02	210.37	322.00	414.28	495.89	575.54	661.86	742.56	816.98	885.01	973.70	1060.99
September	110.05	220.98	327.13	417.23	501.35	578.45	663.92	745.76	820.64	894.86	975.35	1063.10
Annual Total	110.05	110.93	106.15	90.10	84.12	77.10	85.47	81.84	74.88	74.22	80.49	87.75

TABLE 3

Cumulative Watershed Runoff in Inches at the Green River Intake of Tacoma's Gravity Water Supply

Month	1931–32	1932–33	1933–34	1934–35	1935–36	1936–37	1937–38	1938–39	1939–40	1940–41	1941–42	1942–43
October	3.26	76.35	166.03	254.02	315.59	372.03	424.20	485.47	540.89	583.91	617.59	666.17
November	9.05	94.54	175.00	262.68	317.46	372.64	437.14	489.53	544.18	587.44	622.31	673.86
December	13.96	103.18	205.90	271.40	320.65	380.19	446.05	497.52	550.53	592.75	631.09	683.40
January	22.30	115.17	222.27	284.54	330.83	382.16	454.05	507.16	554.07	596.40	633.98	688.68
February	30.94	117.62	227.41	290.75	333.94	385.90	456.66	511.94	561.28	598.76	638.11	694.28
March	45.70	123.86	236.68	296.40	342.13	393.26	461.63	518.98	568.85	601.35	642.27	699.75
April	55.80	131.59	242.00	301.48	351.71	402.48	471.97	526.31	574.09	604.39	648.27	710.19
May	63.99	141.32	244.93	307.74	362.81	411.40	479.96	532.15	579.34	607.03	653.59	717.70
June	69.36	151.65	246.21	311.49	368.11	418.63	482.48	536.20	580.76	609.24	661.00	723.24
July	71.37	155.12	247.06	313.16	369.68	420.89	483.49	537.88	581.60	610.27	663.31	725.44
August	72.47	156.10	247.64	314.13	370.46	422.00	484.16	538.70	582.22	610.99	664.38	726.42
September	73.48	157.99	248.36	314.79	371.23	422.85	484.64	539.43	582.79	612.79	665.04	727.12
Annual Total	73.48	84.51	90.37	66.43	56.44	51.62	61.79	54.79	43.36	30.00	52.25	62.08

TABLE 4

Miscellaneous Runoff and Precipitation Data at Green River Watershed

October 1 to October 1	Mean Runoff *sec.ft.*	Maximum Runoff *sec.ft.*	Minimum Runoff *sec.ft.*	Mean Discharge per sq.mi. *sec.ft.*	Precipitation *in.*	Runoff From Watershed *in.*	Ratio of Runoff to Precipitation, %
1931–1932	1250	16,700	154	5.41	110.15	73.48	66.6
1932–1933	1440	15,200	100	6.23	110.93	84.51	76.2
1933–1934	1537	26,700	81	6.65	106.15	90.37	85.0
1934–1935	1130	12,400	115	4.69	90.10	66.43	73.7
1935–1936	958	5170	107	4.15	84.12	56.44	67.0
1936–1937	879	4460	112	3.81	77.10	51.62	67.0
1937–1938	1052	11,600	88	4.55	85.47	61.79	72.3
1938–1939	933	5060	96	4.04	81.84	54.79	67.1
1939–1940	736	4620	100	3.19	74.88	43.36	58.0
1940–1941	511	6740	110	2.21	74.22	30.00	40.4
1941–1942	889	6300	109	3.85	80.49	52.25	65.0
1942–1943	1057	7530	106	4.58	87.75	62.08	70.8
For the 12-year period	1031	26,700	81	4.45	1063.1	727.12	68.39

Momentary Maximum Discharge—33,600 sec.ft. on Dec. 9, 1933.

accepted theory that the rainfall in the mountains increases with altitude. Lester is located at an elevation of about 1,615 ft. A few isolated precipitation readings taken at Stampede near the divide seem to compare more nearly with those taken at the city's intake. The average precipitation in Tacoma is about 37.27 in. per annum.

During 1933–34, the period of greatest runoff, there were 64 days with turbidities in excess of 10 ppm., while during the period of lowest runoff in 1940–41 there were also the lowest number of days with turbidities of over 10 ppm., namely fourteen days. The average number of days per year during the last twelve years with turbidities in excess of 10 ppm. was 34. The greatest number of days per year when the water showed perceptible color due to decaying vegetation or melting snow was 104 days, while the lowest number was 29 days, and the average for the twelve-year period 70.7 days.

The development of storage in the Green River watershed to overcome turbidities and to supplement low water periods has been given some study by the department. While only a comparatively small amount of storage is necessary, the three dam sites that have been surveyed by the engineers of the U.S. Geological Survey, under the direction of the water department, indicate that comparatively high dams are required to furnish this small amount of storage. Because of the close proximity of the Northern Pacific railroad to the main river, the storage sites investigated are located on the tributaries to the main river. The grade on these tributaries rises very rapidly, making unit cost for any storage development rather high. For some years to come, the storage requirements on the Green River water supply system will, without a question, be provided from the city well system. The well system can be expanded in small units in step with increasing demand and without heavy capital investment.

The unusually high average runoff of 68.3 per cent and the short lag between precipitation and runoff indicate and emphasize very clearly the necessity of maintaining a maximum of forest cover on the entire watershed area. The scant cover of surface soil on the rocky mountain slopes can only absorb and hold a limited proportion of the total precipitation.

Raphael Zone has this to say in reference to forest cover in his U.S. Department of Agriculture bulletin: "The action of mountain forests in protecting the soil against erosion and increasing underground seepage at the expense of runoff is the result of their ability to lessen the severity of rainfall, to retard the melting of snow, to offer mechanical obstacles to surface runoff, to hold the soil together, to keep it in permeable state, to increase its volume by constantly adding new soil and to absorb large quantities of water by its leaf litter." Quoting further from the same bulletin, he states that "A group of prominent hydrographic engineers of Europe had reached the following unanimous conclusions upon these points: first, forests increase the mean low water levels and make their flow more uniform at ordinary stages; second, when situated on impermeable soils and slopes, forests form and maintain springs. Forests hold the soil on slopes and so prevent destructive erosion and its consequences."

In other words, the moderating effect of forest cover on stream flow is to equalize the flow throughout the

year by making the low stages higher and the high stages lower.

With the possible exception of some 5,000 acres along the river banks, all lands in Green River watershed area are chiefly valuable for forestry purposes only. The federal government has so far made little progress in the acquisition of lands so as to consolidate its holdings, mainly due to lack of purchase funds. Without a question, the solution for the preservation and protection of Tacoma's water supply can only be found through a long-range plan administered by a centralized authority looking toward a sustained-yield forest management operation. The city of Tacoma is not in a position to acquire any considerable area of the watershed lands. Over 100,000 acres, or about two-thirds of the entire watershed, is now under control of the Snoqualmie National Forest, the Northern Pacific Railway Co., the Weyerhaeuser Timber Co. and the state of Washington. Fortunately for the city of Tacoma all these four agencies are interested in a long-range forest program, and it is hoped that they will form the nucleus for a centralized organization. Until very recently legislation has been lacking whereunder federal, state and private agencies might pool their interests and make possible the better and more economical utilization of the forest resources. Such a central organization would discourage destructive lumbering on the many small areas of privately-held forest lands and would also strengthen and tend to perpetuate the economic structure of such cities as Tacoma and other communities which depend to a very large extent on forest resources for their industrial economy.

A bill that has been actively supported by the Tacoma Water Department and which will provide the legal machinery for setting up an organization as outlined has finally been passed by the present Congress after a long struggle. The principles embodied in this bill have been the subject of careful and expert study for more than ten years and have been approved by many special and private agencies. This bill, known as Senate Bill 250, was signed by the President on Mar. 29, 1944. The purpose of this bill is to promote sustained-yield forest management in order thereby (a) to stabilize communities, forest industries, employment and taxable forest wealth; (b) to assure a continuous and ample supply of forest products; and (c) to secure the benefits of forests in regulation of water supply and stream flow, prevention of soil erosion, amelioration of climate and preservation of wild life.

It is felt by the author that this bill climaxes the long and persistent effort by many individuals and organizations that have had at heart, not only the best interests of the forest industries for the future, but all have had in mind the preservation of our most priceless heritage—our public water supply.

Acknowledgments

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Water Hammer

By J. C. Stevens

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Presented May 13, 1944, at the Pacific Northwest Section Meeting, Olympia, Wash.

THE effect of the propagation of pressure waves in closed conduits containing water has come to be known by the rather homely name of "water hammer." If a self-closing valve at the washbowl or kitchen sink becomes loose and snaps shut, a chug is heard and felt, as if some one had hit the pipe with a hammer. This chug doubtless is responsible for the term "water hammer," which has become a generic one, meaning not only the effect but also the entire phenomena of wave propagation in closed conduits.

In the design of penstocks and governors for water turbines, the effects of water hammer must be carefully considered. On change of load, the governor action, in causing the turbine gates to close or open, must be regulated to result in the least possible amount of water hammer in the penstocks; and they in turn must be designed strong enough to withstand the shock of such water hammer as is inevitable in such works.

It is to the credit of the turbine and governor manufacturers that no known penstock rupture can be directly attributed to normal operation of such machinery. Actual data on such accidents as have occurred are difficult, often impossible, to obtain, but such information as is available indicates that damages from accidents of this nature have resulted from some emergency condition not contemplated in the design or from some pure "bone head" act on the part of a careless or uncoached employee.

Two of the 66-in. penstocks of the Moccasin Creek hydro-electric plant on the Hetch Hetchy water supply project of the city of San Francisco were ripped open in the early hours of June 30, 1925, while the plant was under test. An operator opened the penstock gate without first opening the bypass to fill the pipe between the gate and the impulse wheel. The penstocks are about a mile long and operate under a static head of over 1,300 ft. The resulting damage amounted to $50,000 and loss of a month's service.

It is well enough to call this a "bone head" play on the part of the operator but it may quite as well be called a "bone head" act on the part of the designers for failure to provide proper interlocking safety devices.

A rupture of a manhole on the penstock of Big Creek No. 8 plant of the Southern California Edison Co. occurred Aug. 20, 1921, caused by water hammer created during the testing of the plant. The single unit of 22,500-kw. capacity was carrying a load of 15,000 kw. on governor control. A short circuit occurred at 6:00 A.M.; the gates were opened by the governor, adding 10,000 kw. to the load on the unit. The short cleared immedi-

ately and the turbine gates closed, setting up a severe water hammer. The penstock is 2,800 ft. long and varies from 6 to 8 ft. in diameter. The static head is 680 ft.

This was an emergency condition and probably would not have caused damage had it not been for a slag pocket in the cast-steel ring of a manhole on the penstock.

Water hammer must be guarded against in the design of discharge pipes from pumping plants. Pumps are usually provided with check valves to prevent the water in the pipe from running the pumps and motors backwards with consequent damages. The closing of the ordinary swing-check valve does not occur until the flow has started to reverse, whereupon the shock of closing produces a succession of pressure waves that traverses the entire length of the pipe from check valve to reservoir many times, each wave decreasing in amplitude until damped out by friction. Figure 1 is a typical case. Certain types of quick-closing valves on the market will reduce the water hammer effect materially but cannot eliminate it altogether.

Fundamentals

The phenomenon of water hammer is caused by the sudden transformation of kinetic to potential energy. Consider the simple case of a pipe of uniform diameter, with walls of the same thickness and of the same material throughout, carrying water from an open reservoir. If the flow is held steady and uniform by a partially closed valve, a condition of equilibrium exists in which the forces of gravity and the energy represented by the difference in pressures at each end of the prism of water are exactly balanced by the friction of flow, as shown in Fig. 2.

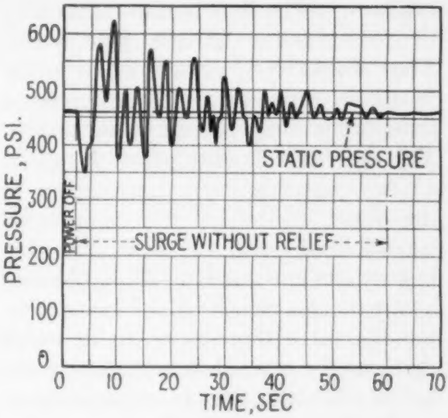

Fig. 1. Pressure-Time Curve Without Suppressor

If the valve is suddenly closed completely, in an instant the condition is as shown in Fig. 3. A portion of the prism next to the valve of length X will have had its velocity reduced to zero, while the remainder of the prism is still flowing at its original velocity. The pressure on the upstream end of the prism X is therefore increased, as evidenced by the rise in the piezometer pipe at section 2 by an amount y. At this instant the pressure line on the pipe is represented by the line "a b c," the pressure head throughout the entire length X being constant at $h + y$ and the velocity zero, while on the remaining portion the pressure head is h_2 and the velocity V downstream.

The front of the compressed prism X moves upstream at a velocity c, called the celerity of wave propagation, until the entire water prism in the pipe has come to rest under a pressure head of $h + y$. During this time the pipe walls have stretched under the strain, enlarging the pipe. The instant the front of the compressed prism reaches the reservoir, water starts to flow into the reservoir because the head $h + y$ is greater than the head in the

reservoir. The flow is also induced by the compression of the pipe walls. Thus a velocity V is established in the upstream direction and the pressure head drops to its normal value or less. The upstream flowing prism X_1 (Fig. 4) now extends itself downstream to the valve, cancelling the compressed condition of water below it. At this instant the entire prism X_1 is flowing upstream at a velocity V. Upon reaching the valve there is no more water that can be started flowing upstream but as the water tries to continue flowing in that direction a partial vacuum is formed at the valve, which creates a prism of subnormal pressure as shown in Fig. 4, for which the pressure head is represented by the line "d e f." This prism, designated by X_0, extends itself rapidly upstream, halting the upstream flowing water and reducing the pressure to y below normal. When this prism reaches the reservoir, the entire prism is at rest under a uniform head of $h - y$ and water again enters the pipe because the head $h - y$ is less than that in the reservoir. This establishes a downstream velocity V and the entire cycle is repeated over and over. This process is facilitated by the expansion and contraction of the pipe walls, as well as the expansion and contraction of the water itself, under the imposition and relief of stresses.

At any given section in the pipe there is thus set up a series of pressure oscillations around the normal, which continue until they are damped out by friction of the water velocities propagated in both directions in the pipe and by the molecular resistance to repeated expansion and contraction of the pipe walls. This is shown in Fig. 1. by the pressure-time curves.

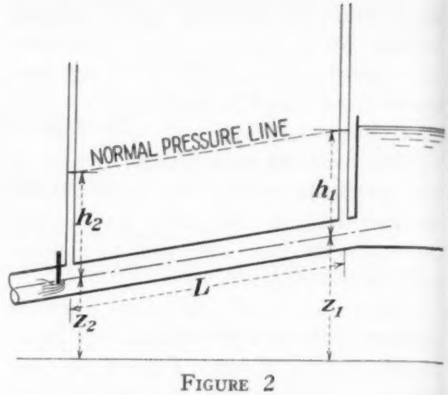

FIGURE 2

If the valve had been suddenly opened wide instead of being closed, the water would have accelerated to some value V' instead of having its velocity arrested. A subpressure wave would then first have traversed the pipe. When it reached the reservoir the pressure head in the reservoir remaining at normal starts a normal velocity wave down the pipe with a corresponding normal pressure head. The velocity then oscillates from V to V' until the new condition of flow at V' has been established with its steeper energy gradient.

There must be something in the pipe to reflect the pressure waves. Experience has shown that a partly closed valve, a change in diameter or in thickness of walls, a change in pipe material, or a valve housing, even though the gate is wide open, all may serve as reflecting agencies that may cause partial reflections to be superimposed on the principal ones, resulting in complex pressure waves such as those of Fig. 1.

Pressure Rise

From Fig. 2, the Bernoulli equation of energy can be written. When the equilibrium is destroyed by the valve, closure momentum is being de-

stroyed and this change of momentum is a measure of the forces producing the change. This force is indexed by the rise in pressure. By such an analysis the pressure rise due to sudden gate closure has been found to be

$$y = \frac{cV}{g} \tag{1}$$

where y is the pressure rise above normal; V is the original velocity of the water; c is the celerity (velocity) of wave propagation; and g is the acceleration of gravity. Obviously, the length of time required for a wave to traverse the pipeline of length L from valve to reservoir and return is $2L \div c$. It may be shown that as long as the valve is closed within the time interval $2L \div c$ the pressure rise will be the same as if closed instantaneously. That is, the pressure rise is independent of the time and manner of closing the valve so long as it occurs within the time interval $2L \div c$ seconds which, for brevity, is called the "pipe period." If closed in successive steps the pressure rise for each step is

$$\Delta y = c\frac{\Delta V}{g} \tag{2}$$

where ΔV is the change of velocity due

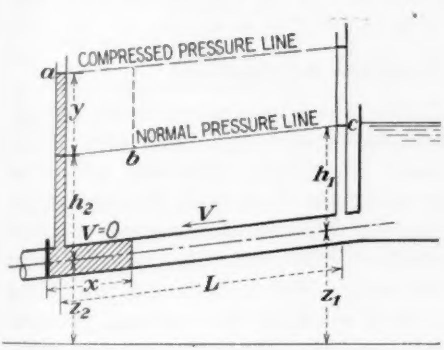

FIGURE 3

to a step closure of the gate and Δy the corresponding pressure rise.

If the step closures are timed to occur in more than one pipe period, the pressure rise will be less but its determination becomes quite complex.

Celerity of Pressure Waves

In order to evaluate the above formulas we must know the celerity or the velocity of wave propagation. Since sound is the result of the propagated pressure waves, the celerity of the pressure wave is that of the velocity of sound in the medium in question.

The celerity of wave propagation in any closed conduit depends upon the modulus of elasticity of the pipe walls in tension and also on the bulk modulus of the water in compression. The formula that has been derived is

$$c = \frac{4720}{\sqrt{1 + \frac{KD}{Et}}} \tag{3}$$

in which K = the bulk modulus of the water (about 300,000 psi.); D = pipe diameter; t = thickness of pipe walls; E = modulus of elasticity of the pipe material (about 30,000,000 psi. for steel). The numerator is the velocity of sound in an unconfined body of air-free water in feet per second.

Example

Consider a pipe 36 in. in diameter, of $\frac{1}{4}$-in. steel plate a mile long under a normal head of 100 ft. flowing full. From (3) the celerity of wave propagation therein would be 3,000 fps. From (1) the increase in pressure head due to instantaneous closure of a valve with normal velocity of 10 fps. would be 930 ft. or a pressure rise of over 400 psi. above normal! If the normal velocity were only 1 fps. the

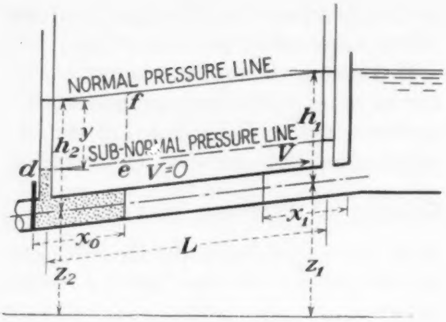

FIGURE 4

pressure rise would amount to 40 psi. This illustrates the enormous force due to water hammer and how unthinkable it is to close instantaneously a valve in any pipe carrying a flow of water. Fortunately instantaneous closure of any type of valve under a head is next to impossible. For this pipeline $2L \div c = 3\frac{1}{2}$ sec. and the pressure rise will be the same whether the valve is shut instantly or is gradually closed within the $3\frac{1}{2}$-sec. period.

Historical Review

The above formulas were first derived and experimentally verified by Prof. N. Joukovsky of Moscow in 1898. His treatise was translated by Miss Olga Simin and published in *Proceedings A.W.W.A.,* 1904, p. 341. The Joukovsky formulas cover only the simple cases. The complexities due to slow valve closure were not covered.

In 1902 Lorenzo Allievi, an Italian civil engineer, published a monograph in Italian entitled "General Theory of the Variable Motion of Water in Pressure Conduits." This work was expanded in 1913 to include practical application to the specific problem of water hammer. Allievi's work has been translated into many languages. His work contains diagrams by which the pressure rise in simple conduits may be found for uniform gate closures of varying time intervals. Allievi's treatise forms the basis of all our present theories of water hammer and has been extended by Robert E. Glover to include compound pipes; by Eugene E. Halmos to include surge tanks; and by Ray S. Quick to include discharge pipes from centrifugal pumps.

Norman R. Gibson published the first important treatise in English on water hammer entitled "Pressures in Penstocks Caused by the Gradual Closing of Turbine Gates" (Trans. A.S. C.E., **83**: *707* (1920)). By assuming the gate to be closed in a series of small instantaneous steps at time intervals equal to the pipe period, Gibson succeeded by arithmetical integration in determining the pressure rise. His results check almost exactly with those obtained from the Allievi diagrams, although the authors' works are entirely independent of each other.

A symposium on water hammer was presented at Chicago in June 1933 jointly by the Hydraulic Division of the American Society of Mechanical Engineers and the Power Division of the American Society of Civil Engineers. This constitutes the bible on water hammer in English at the present time. It was published as a bulletin by the A.S.M.E.

Practical Applications

The above outline of fundamentals and the example apply to a very simple case. In practice pipelines are often compounded of several diameters and include different thicknesses of plate and not infrequently entirely different materials. For example, a compound pipe of wood for the low-head portions and steel of smaller size for the high-head portions are frequently adopted.

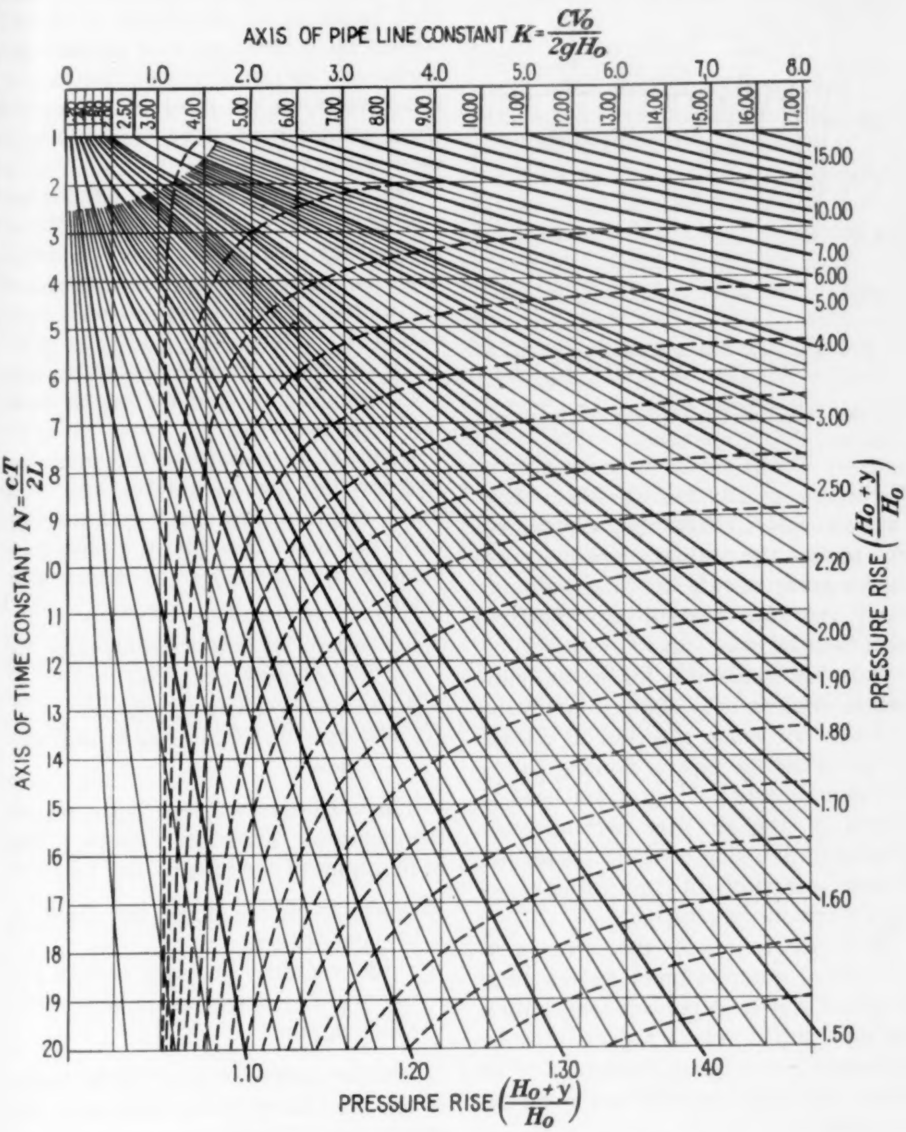

FIG. 5. Chart for the Determination of Maximum Pressure Rise for Uniform Conduits—Dotted Lines Indicate Interval at Which Maximum Pressure Rise Occurs (Reprinted from *Theory of Water Hammer*, by L. Allievi)

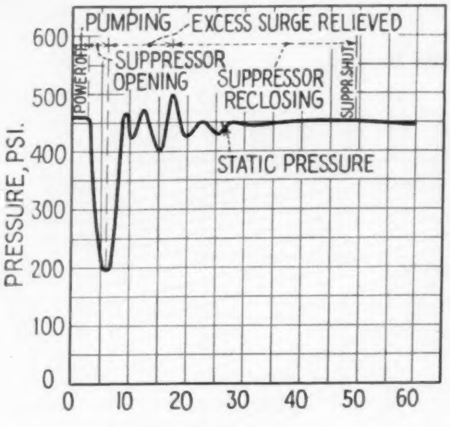

Fig. 6. Pressure-Time Curve With Surge Suppressor

There are usually branch lines, services, air valves, blow-offs, standpipes, etc., so that the ordinary pipeline presents a great complexity of conditions which are far beyond any possible mathematical solutions.

It is not impossible for water hammer to be caused by trapped air in the pipe—an air valve may fail to release the air while the pipe is flowing partly full at a summit. If an extra head is turned in, the air may become compressed until a slug of water passes the summit, carrying out the air and causing a surge in the pipeline.

In order to avoid excessive pressures from water hammer, valves must be closed slowly in periods longer than the pipe period; check valves must be cushioned; and often automatic relief valves or surge suppressors must be provided.

An old rule of thumb that has been applied to short lines under low heads is to add 50 per cent to the normal operating head to allow for water hammer. This is probably safe for ordinary lines where only a moderate amount of water hammer may be anticipated. On long pipelines under high heads on which pumps or water wheels are located no such percentage increase is permissible but the maximum stress for the most critical operating condition must be painstakingly worked out.

On compound pipes an equivalent pipe of uniform diameter may be substituted for purposes of water hammer analysis. The gate movements must be limited to safe time intervals and automatic interlocking devices provided in order that gate operations are not possible except in the one chosen safe sequence.

In order to determine the pressure rise for any rate of gate closure, Allievi's diagram shown in Fig. 5 may be used. In order to apply it, a pipe constant $K = cV_0 \div 2gH_0$ is determined where

c = celerity of water propagation as heretofore explained
V_0 = normal velocity in pipe
H_0 = normal head for steady uniform flow

This quantity is shown at the top of the diagram. Time intervals are given in multiples of the pipe period, i.e.,

$T = n2L/c$ where T is the time of gate closure
n = the number of pipe periods = $Tc/2L$ shown on the left of the diagram.

The pressure rise is given in terms of the rise above the normal head for steady flow. These are represented by the diagonal lines. The former example of pressure rise in a 36-in. pipe, under normal head of 100 ft., carrying water at a velocity of 10 fps. is now readily checked by the diagram.

The pipe constant $K = 3{,}000 \times 10 \div 64.4 \times 100 = 4.65$. The time period

for the 1-mi.-long pipe is $3\frac{1}{2}$ sec. From Fig. 5 for the above pipe constant and one time period find $(H_0 + y) \div H_0 = 10.20$, since $H_0 = 100$ ft., $y = 920$ ft. for the pressure head rise which checks closely with the value previously found. If the normal head had been 75 ft., then $K = 6.2$ and $h = 923$ ft. Hence the pressure head rise is practically independent of the normal head for steady flow for closure in one pipe period, as is evident from (1).

For closure in longer periods, however, the normal head has a decided effect as the following will show:

For $H_0 = 100$, $K = 4.65$. Let $n =$ six periods. Finding the intersection of $n = 6$ with $K = 4.65$, read $(H_0 + y) \div H_0 = 2.10$, from which $y =$ 110-ft. rise.

For $H = 75$, $K = 6.2$ $(H_0 + y) \div H_0 = 2.65$, for which $y = 124$ ft.

If the pipe had been designed to withstand a head 50 per cent in excess of normal, we have for $H_0 = 100$ ft., $(H_0 + y) \div H_0 = 1.50$, for which n is found to be eleven periods, that is, $38\frac{1}{2}$ sec. should be the time of gate closure.

On long pump discharge lines a surge suppressor may be installed as a safety measure. It is merely a glorified relief valve attached to the branch of a tee just beyond the check valve. If power fails the valve is opened to bypass the water under the pressure head rise to the pump sump. Thereafter the valve slowly closes, bringing the prism of backward flowing water in the pipe to rest. Figure 6 shows the effect of a surge suppressor made by the Pelton Water Wheel Co. on the discharge line of a high-head pump. Figure 1 shows the water hammer in the same line without the surge suppressor due to a power interruption.

For a discussion of other corrective measures to reduce water hammer, reference is made to an article by Richard Bennett in *Water Works and Sewerage,* June 1942, entitled "Water Hammer Correctives."

Interruptions of Electrical Supply to Water Works Plants

By A. C. Hutson

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Presented on Nov. 4, 1944, at the New Jersey Section Meeting, Atlantic City, N.J.

IN 1927, R. C. Dennett and George L. Swan, engineers of the National Board of Fire Underwriters, presented a paper entitled "Reliability Features of an Electrically-Operated Pumping Station." * In this it was brought out that there was a decided trend toward electrical motors as prime movers in connection with the varied operation of water works systems. In addition many industrial plants are depending on electricity for the operation of production machinery and have no other power for local plant fire protection.

It is evident that a major interruption of electrical supply in any community may be very serious. There is not only a possibility of private plant protection being put out of service, but also the municipal protection may be materially reduced, if not entirely eliminated.

It is possible to provide standby or emergency service, insofar as pumps are concerned, through the installation of internal combustion engines and a supply of oil in storage. There may be other equipment in a municipal plant, such as individual well pumps, a soda feeder, or revolving screens or agitators which must be kept in operation. These may make it necessary to install reserve generators, operated by internal combustion engines.

The natural inclination would be to have these reserve internal combustion engines such that they could be economically operated for a considerable period of time, and for that reason the diesel type appears to be favored by many water works officials.

Under most conditions interruption of electrical supply will be short, and therefore the first cost of the emergency equipment may be important. Fire departments have proven beyond any doubt that the automobile gasoline engine, with a centrifugal pump, designed to operate at 2,000 to 2,500 rpm., is a very satisfactory piece of equipment for such service. These have been developed for operating pressures of 100 to 250 lb. and it appears reasonable that pumps can be designed for large quantities at the low heads used in the usual filtration system.

One of the prime requisites of any water supply system depending on electricity for pumping, irrespective of whether the system supplies a community or provides fire protection to a large industry, is to have some elevated storage. It is desirable, even if there is standby equipment, to provide some storage to take care of electrical outage. Small elevated tanks will care for the momentary shut-downs, such as occur during electrical storms, but as the cost of this type of tank is not high it is best to provide storage that will

* J.N.E.W.W.A., **41**: 268 (1927).

allow for several hours of shut-down and still leave a good supply for fire protection.

The following exemplify some of the more serious interruptions in electrical supply to communities. Many of them did not affect fire protection but they are given as an indication of the probability factor which must be considered when operation by electricity is being contemplated.

Examples of Electrical Outages

The question of strikes interrupting electrical supply to water works is one of vital importance. A news item, dated September 17, 1941, reported that Kansas City, Mo., was without lights and power and virtually without water as employees of the Kansas City Power and Light Co. struck at midnight with virtually no warning.

Several major interruptions to electrical service have occurred in areas supposed to be so inter-tied with other systems, or with other generating stations, that there could never be a serious interruption of service. Probably the most important of these was the breakdown of service for a portion of the Borough of Manhattan in New York City. A ground fault on a bus at the Hell Gate generating station resulted in the complete destruction of two sections of the switch house, a bus compartment, and a small room containing ground disconnect switch and circuit breakers for four generators; some feeders were severely damaged. Ties to other systems were damaged, thus interrupting all 60-cycle supply from this station. Repairs permitted a portion of the area served to return to normal in about 1 hr., and conditions in other areas were progressively corrected, with normal service in about 11 hr. During this time attempts to supply the major area affected, through feeders from other stations, resulted in overloading feeders, transformers and secondary mains, and in a general condition of low voltage over a large area.

Outage in Washington, D.C.

On Dec. 21, 1940, at about 7 A.M., the electric supply for Washington, D.C., was seriously interrupted.

Washington has two steam-powered generating stations, developing about 170,000 kw. each. Also, three outside connections for electric power come into the city from the north—one is a small line coming in through Takoma Park, Md., one is through the Pennsylvania Railroad electrified railroad system and the main and largest one is from a water power generating station at Safe Harbor, Pa.

A short in some equipment at Safe Harbor, at a time when Washington was receiving its main supply from Safe Harbor and only one or two Washington generators were operating, resulted in an indication of trouble which at first was believed to be at the steam generator station. The generators at the Washington station were shut down until the short was located. Current was off in sections of Washington and Baltimore for periods up to $\frac{3}{4}$ hr. and in some outlying sections for longer periods.

Outage in Essex County, N.J.

The Essex Station of the Public Service Electric and Gas Co. is located in Newark, N.J. It is a modern, base-load steam station generating 13.2 kv., 3-phase current with a rated output of 214,444 kva. This station is tied in with Kearny base-load steam station, also generating 13.2 kv., 3-phase current, through an outdoor sub-station.

Shortly after 3:30 P.M. on Dec. 28, 1936, while the station was in normal operation, one of the insulators on No. 1 selector oil switch broke down, allowing the current to ground through the outer casing and frame of the switch. This was a 3,000-amp., 15,000-v., 3-phase oil switch with three tanks containing from 50 to 65 gal. of oil each, all of which were located in a masonry cell at the south end of the fifth floor. It was used for the purpose of tying in the 13.2 kv. received from Kearny station to No. 1 generator bus located on the sixth floor.

After the insulator broke down the current grounded to the oil tanks, causing the oil to ignite, thus forming a heavy smoke and ionized gases. The smoke and gases spread rapidly to an adjacent masonry cell containing No. 2 selector oil switch and caused this switch to ground but it was not damaged. The smoke and gases spread through floor bushings, etc., to the sixth floor. It penetrated to the No. 1 generator bus chamber where it collected in a form of carbon soot on the bus and insulators, causing a secondary breakdown at this point, with damage to several supporting insulators. The grounding of the frames supporting the oil switch to the structural steel frame of the building permitted the current to pass to the neutral ground from the generators and ruptured the oil switch, shunting the 2-ohm resistance in the ground connection.

Some difficulties were experienced in combating this fire because of the intense heat, smoke and stifling fumes. It was necessary to clear the station of electric current. After burning for about 3½ hr. the fire was finally extinguished. The soot from insulators, buses, etc., had to be cleaned off before service could be restored.

Electric Outages in the South and Midwest

In 1941 the entire electrical supply for the city of Jackson, Miss., was out of service for a period of 1½ hr. The entire municipal water supply was dependent upon electric current. Three 5,000-kva., 11,000–13,000-v. transformers, under a load of 10,416 kv., were involved. There was a fourth spare transformer. All three transformers, as well as considerable control equipment, suffered breakdowns, with a fire ensuing in the oil-filled equipment. It was 1½ hr. before a steam plant with cold boilers could be started up and 4,000 kw. in generators put in service.

At Tucson, Ariz., on Aug. 14, 1940, a heavy rain of 2.35 in. within an hour caused a flood which put out of commission the main power plant, requiring an auxiliary plant at Cortaro to be placed in operation. This required some 4 hr. The supply was only 1,500 kw., about 10 per cent of the demand, and full service was not restored for three or four days.

In Jonesboro, Ark., about 1940, a burn-out in some oil-cooled switches in the switching room of the Municipal Power, Light and Water Plant caused a shut-down of the entire electric system for a period of about 2½ hr. The water system was not totally disrupted for the period of the shut-down, since they had in reserve a 1,500-gpm., steam-driven, reciprocating water pump. This was immediately placed in service and drafted water from the ground storage reservoir, which was of sufficient capacity to maintain some fire service during the shut-down period. The system is dependent on two pumping plants, one at the power plant and one suburban station. This latter station is entirely electrically

driven and naturally it was out of service until the electric plant was returned to service. This caused a lowering of pressure in certain sections of town but did not seriously affect the adequacy of the system.

About six years ago a small community in northwestern Arkansas had the entire water system out when a fire burned down the electric lines which supplied the current for the operation of the municipal pumping plant. Arkansas has experienced a number of other interruptions to electrical service to water systems due to transformer burn-outs.

About six years ago, the city of Monticello, Ark., was completely out of water for about 24 hr. when lightning struck the high-tension transmission line and burned out a large bank of transformers. The situation was rather serious in this municipality, since they had no elevated storage to serve as an emergency supply.

A serious interruption of electrical supply in Minnesota occurred following the Armistice Day blizzard in 1940, when many of the municipalities dependent upon high line supply were without current for periods ranging from minutes to as much as 56 hr. The town of St. Charles, Minn., having a population of 1,500, was most severely affected. Records indicate that over 90 per cent of these smaller cities depend on electric power as their only prime mover in their water supply system. Many communities found it necessary to shut off their elevated storage tanks and maintain that water for fire reserve.

In December 1941 a less severe storm caused high line failures for a few small cities and towns in the eastern part of the Dakotas and western Minnesota. The periods of interruption in this instance lasted less than half a day in all towns affected.

In June 1933, the entire milling district of Minneapolis was cut off for from 8 to 17 min. and several minor residential areas were out for as long as 3 hr. This interruption was caused when a lightning discharge burned out a current transformer, flashed the potheads in a large switching station and destroyed the oil-filled disconnects.

On Jan. 9, 1942, a severe fire in the high-value district at Waseca, Minn., destroyed the main outgoing feeders from the municipal plant and caused current interruption of almost 7-hr. duration to a large part of that city.

In Kansas a city was without water power for 38 hr. because a sleet storm broke down the electric transmission lines. In another instance, a city was without water for 12 hr., because the main supply line broke at the edge of town. In 1938 a circuit breaker failed in Kansas City, Kan., and caused a $23\frac{1}{2}$-min. shut-down at the electric plant. Some years ago a fire destroyed the water and light plant at Garnett and the town was without electricity for several weeks, but the pumps were steam driven and were repacked and put into service within a few days. Salina and Atchison both had major gas pipe failures that left them without a gas supply for several hours.

Approximately fourteen years ago at the Market Street generating station of the New Orleans Public Service, Inc., a valve in a turbine stuck and power supply for practically the entire city was disrupted for a period of something less than an hour. About four years ago there was a 15-min. shutdown at the same station, resulting from a short circuit on a bus. There is an ever-present possibility of failure in numerous towns and cities in Loui-

siana. Single generating units and single banks of transformers are the general rule in many of the smaller municipalities. The water supply is often entirely dependent on electric service, and in some cases generating equipment and pumping equipment are housed in the same building.

In Omaha, Neb., at about 6:30 P.M., Apr. 2, 1941, a boy flying a kite caused a short in the high-tension wiring near the Bedford Avenue substation which resulted in a complete breakdown of the electrical supply to the Minne Lusa pumping station. The pumps were out of service about 45 min.; the electric lights in the pumping station were out about 15 min.; power was generated for the light circuit by a small generator in the Minne Lusa pumping station. Normally, the automatic switch located at 108th Street near Maple Street would have kept the circuit in service, but in this case it was necessary to have the switch thrown in manually; this required about 45 min. In the meantime, the full repumping load was thrown on the Poppleton Avenue Station. Despite light consumption, the water pressure was low in several portions of the city covering a period of about 1 hr. Sometime during 1940, a short on the supply side of the large transformers outside and adjacent to the Minne Lusa pumping station put the transmission lines out of service for a period of three days. After 1½ hr., the pumps were being operated by steam.

In 1936 a boiler explosion wrecked the Missouri Power and Light Co. plant of Moberly, injured four persons fatally and one other critically and left the city in darkness for 3 hr. Light and power service was restored by cutting the city's system into the lines of company plants at Mexico, Boonville and Jefferson City. Water service was cut off until an emergency engine at the pumping plant was put into operation.

The Texas Panhandle was isolated in 1940 by rapidly thickening coats of ice on communication lines. City water works at Amarillo ceased pumping at 6 A.M. and storage above-ground was exhausted at 4:30 P.M.

In January 1937, the towns of Dyer, Greenfield, Kenton, Martin, Newbern, Obion and Rutherford, all in northwestern Tennessee, were without electric service for several days, as electrical transmission lines were broken down by a heavy sleet storm.

On Jan. 15, 1932, the bank of three transformers connected to the main transmission line serving the town of Winchester, Tenn., was struck by lightning and put out of service. Spare transformers were brought in from several towns, and service was restored in 24 hr. The water pumping station was able to operate because of an emergency connection to a small hydroelectric plant near the town.

About 1928, the dam of the municipally-owned hydro-electric plant, serving the town of Cookeville, Tenn., was destroyed by a flood. At the same time lightning put out of service the electric motors driving pumps in the municipal water pumping plant 8 mi. away. However, water service was maintained by a gasoline-engine-driven pump until the motors were rewound and an emergency electrical connection with the transmission line of a privately-owned utility could be made.

In Athens, Tenn., the transformers connected to the main transmission line serving the town were put out of service by lightning at 1:30 P.M. July 7, 1930. At 9:00 P.M. an emergency connection was made to a 2,200-v. line from a town 10 mi. away, which was able to operate one of the pumps at

about one-half capacity. About 10 A.M. the next day, some other connections were made so that about 75 per cent of the pumping capacity could be utilized.

Approximately 22 in. of wet snow fell in Charleston, W.Va., on March 2, 1942, and in West Charleston the electrical power was out of service for a period of 36 hr. This was due to 24 breaks in lines carrying 44,000 v., which lines were broken down by an accumulation of wet snow. In East Charleston the electric service was intermittent, eight breaks in lines having occurred in that section. There was no secondary source of power for the water supply, but during the period adequate water supply was reserved for fire fighting service, and the domestic supply was intermittent. The water pumping station did not happen to be located in West Charleston where electric power was out of service for the longest period.

About 9:00 A.M. on June 8, 1942, a training plane from the Tuskegee Air Field cut down three 110-kv. conductors of the Tallapoosa River-crossing span of the Alabama Power Co. In the larger cities affected service was restored in from 15 to 21 min. by supplementary steam or oil engine plants, and other utility interconnections; some of the smaller communities were without electrical supply for water works pumping stations for a period of approximately 6½ hr.

In May 1940 a high wind blew down both overhead power lines supplying the water works of Muskegon, Mich. A gasoline-engine-driven pump of 6-mil.gal. capacity and a 1-mil.gal. tank were available for fire supply and to maintain an average consumption demand of 5.5 mgd.

A hurricane in 1942 disrupted power supply to the water works of Savannah, Ga., leaving only a 4-mil.gal. gasoline-driven pump for a supply for over 14 hr.; in this same hurricane the current was cut off at Charleston, S.C., as a life-saving measure, leaving the entire city and several smaller places without power.

On Dec. 30, 1942, the high-tension line supplying the town of Ayer was put out of commission for about 12 hr. by a sleet storm. The town had a standpipe of 600,000-gal. capacity and one water-power-driven pump of 400,000-gpd. capacity. This pump was put into service and it was stated that they were able to supply about 80 per cent of the town's demand.

At Lenox, Iowa, a lightning bolt struck a power line and blew out two power transformers serving the municipal water plant; water in the elevated tank was exhausted a short time before pumping was resumed.

Summary

This record of interruptions in electrical supply is far from being complete. None of the instances cited is so old as to permit one to say that similar events cannot happen with modern electrical supply systems. Even such things as hurricanes cannot be considered as local to certain sections of the country. In the New England hurricane in 1939, many power lines were interrupted, but most of the water systems using electrical power had sufficient elevated storage. In September 1944 another hurricane swept up the Atlantic Coast from the Carolinas to New England, and large areas were without electric service. The most complete interconnection of basic high-voltage power lines does not seem to produce the answer. Other sources of power, primarily internal combustion engines, and greater storage deserve attention.

Disinfection of New Mains

By Cecil K. Calvert

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Presented on November 9, 1944, at the Four States Section Meeting, Philadelphia, Pa.

THERE is a great deal of opportunity for contamination of mains inherent in the handling of pipe and the unavoidable nature of the operation of placing it in the ground. There is no reason why pathogenic bacteria cannot be transmitted in this way. In the water in newly-laid mains, types of bacteria are found which are indicative of pollution, and since laboratory tests cannot determine their origin, it is necessary to take all possible precaution to keep them out or to destroy them where tests show them to be present.

Pipe can go into the ground with dust and dirt in it, the amount depending on how it has been handled and cleaned. The particles of solid matter can enclose bacteria. The flushing operation may be relied upon to remove a great deal of such solids but it is not reasonable to expect it to sweep the inside of the pipe clean. If a hydrant delivers 1,000 gpm. during flushing, the velocity in a 6-in. line is 680 fpm. and in a 20-in. line, 61 fpm. Even the higher velocity is not scouring. Some solid matter will be held on the inside walls of the pipe and in the joints.

The packing material commonly used is hemp, which normally contains a large number of bacteria and is itself a suitable food for a great host of bacterial types. Adams and Kingsbury, who made the first extensive report on hemp from a sanitary standpoint, found that they could culture *Eberthella typhosa* in broth containing no other nutrient material except that extracted from hemp. Many bacteria live on rubber, both natural and synthetic, some of them not growing on ordinary laboratory culture media but comprising, in part, the flora of the water in dead ends and contributing to the taste and odor of the water. Cotton and paper have been used to some extent to replace jute and hemp but both of them fall victims to bacterial action.

In sulfur-compound joint failures, where the compound has become softened, bacteria have been found which are natural in many soils. This action goes on from without but the bacteria causing the failure are ubiquitous, and if they gained entrance by way of the water and penetrated the packing, they would become a part of the life in the main even though they do not add to the routine plate count.

When a person charged with maintaining satisfactory water quality in the distribution system has a new main turned over to him, his problem is complicated by the several factors mentioned above. The general experience has been that no one set of rules when applied to the treatment of a new main will guarantee success in all cases. From published articles, as well as from conversation with water distribution workers, come reports of new mains and entire systems which

are chlorinated again and again before good water is delivered regularly.

When the existence of the difficulty with new mains was first recognized, or rather when attempts were first made to correct it, the general practice was to leave little piles of hypochlorite in each joint as the pipe was laid. If extensive tests of the effectiveness of this procedure had been made, it would have been discarded or changed. A great deal of the chlorine in the powder was lost to the atmosphere as shown by the fact that frequently workmen "forgot" to put it in because it "smelled bad." Leaving the hypochlorite in the line made it impossible to flush the pipe before chemical treatment and any dirt left in it reduced the strength of the chlorine solution. In filling the completed line with water it was difficult to get the workmen to turn the water on slowly enough to prevent washing the powder to the far end of the line at once. This method did not produce good results and there is no reason why it should—but it was a step in the right direction and it did tend to make the construction gang conscious of the need for care in laying mains.

That the problem is a tough one is shown by the usual specification that water containing from 40 to 100 ppm. of chlorine be left in a new main over night. These high concentrations have been used in recognition of the protection afforded bacteria by the solid matter introduced during the handling of the pipe and in the packing material. In clear water, a few tenths ppm. of real chlorine would be as good as 100 ppm.

Packing

Most investigators have assumed that the whole trouble rests in joint packing and have directed their efforts to correcting it. Certainly the old type packing is a major source of trouble even though it is treated with sterilizing chemicals or heat before it is put in place. But the results obtained in many newly-laid mains under what are believed to be controlled conditions seemed to indicate that there must be some other source of contamination in new mains.

While the idea still prevailed that the source of contamination rested in the packing, considerable effort was expended in devising methods of treatment for hemp. Jute was never considered as suitable, either plain or tarred, because plain jute is much dirtier than hemp and the tarred jute has developed chlorophenol tastes in chlorinated water.

Due to the nature of hemp, a simple sterilizing agent is not suitable because extractives, after the effect of the treatment is gone, sustain bacterial life. Clearly, an agent is indicated which will maintain a continuing bactericidal or bacteriostatic action. A suitable chemical agent must penetrate the fibers completely and mordant itself there to such an extent that constant exposure to water will not remove it.

By chance, a material was found which exhibits these characteristics to a considerable degree. It is ortho-mercuro-phenol and is sold under the trade name of "Klerol" for disinfection purposes. Hemp treated with Klerol at a rate to deposit 3 mg. of mercury per gram of hemp held bacterial counts low for many months. The next best treatment was soaking the hemp for several hours in 15-per cent copper sulfate and then rinsing and soaking in 10-per cent sodium carbonate. The 15-per cent strength of copper was

chosen because preliminary tests showed that 10-per cent was rather ineffective and 25-per cent left the hemp too stiff. The deposited copper carbonate on and within the fibers retarded bacterial growth to a very great extent for the 10-month period of observation.

There are two general conditions imposed on the water in new mains with an infinite variety of gradations between the two extremes of (1) dead ends and (2) active transmission lines. In the former there is natural multiplication of bacteria which may take place in water, plus that induced by food material in the pipe lining or in the jointing material. In the latter condition, the time in the line may be so short and the quantity of water may be so large in proportion to the main wall area that an almost unmeasurably small bacterial increase will take place.

In established distribution systems, very few of the newly-laid mains are active immediately, most of them being extensions into sparsely built-up districts where water use is small. This most severe condition was investigated in lines laid in a variety of ways.

It was soon learned that samples from fire hydrants were unsatisfactory because the leather in the valve is bacterial food. For use on lines under test, there was made a special sampling tap of sterilized pipe fittings with a sill-cock valve which was fitted with a lead washer instead of a fiber one. Between samplings, its outlet was protected by a cap filled with alcohol. These precautions were taken to make sure that the sample drawn was representative of the water in the line. The following "case histories" were obtained on samples taken in this manner.

Examples of Pipe Sterilization

A line with no prior treatment of pipe or hemp was laid in August. It was chlorinated at once and allowed to stand for 48 hr. at which time the water contained in it had a chlorine concentration of more than 90 ppm. Samples taken after all trace of chlorine was gone gave counts of less than ten and no gas-former was found in fifteen 10-ml. portions. Twenty-one hours later, the counts were about 500 and coliform organisms were present generally in 1-ml. amounts.

The coliform density continued, with counts of several thousand for some weeks. Heavy flushing reduced both coliform organisms and total bacteria but did not reduce them to the level in the water being supplied to the line.

In mid-October, 56 days after laying, coliform organisms were decreased but still frequently found in 1-ml. amounts and the counts were just under 1,000.

Two lines were laid in the same district at about the same time in mid-October. They were sampled for two months. One line was laid with hemp treated with 1-25 Klerol and the other with hemp treated by soaking in 15-per cent copper sulfate solutions to which had been added enough ammonia to re-dissolve the precipitate formed initially. The pipe used in both the lines was swabbed with 1-25 Klerol just before laying.

Coliform organisms were not found in samples from either of the new lines during the period of the test. The counts on the day after the lines were finished were very low. On subsequent days they rose but not to the figures obtained in the summer and earlier in the fall. At the end of 60

days they were normal in the water from both lines.

Samples of the treated hemp used in both lines were tested by the "three-day cycle" method, giving perfect results. It must be assumed that the lowered water temperature produced an inhibiting effect on bacterial multiplication.

Two lines were laid with tubular-rubber packing, neither the packing nor pipe being treated. In one line the counts were somewhat elevated from the first but coliform organisms were absent immediately after the first flushing. In a day or so coliform organisms appeared and the counts were in the low thousands. In 12 days, coliform organisms disappeared and no more were found for the duration of the test which lasted six weeks. No coliform organisms were found in the water being supplied to the new line. At the close of the test, the counts were lower but they were still higher than in the water entering the line.

In the other untreated line, coliform organisms were present from the first and the counts were quite high. At the end of five weeks, when the test was ended, the coliform density was greatly reduced but the counts continued high.

Thus, by chance, no treatment at all produced fair results in one case and decidedly poor conditions were found in the other.

A line was laid with 1-25 Klerol-treated tubular-rubber packing in the joints and each length of pipe was swabbed with Klerol of the same strength as was used on the packing. This was early in August with water temperature at about 75°F.

On the day following completion and filling of the line, it was sampled five times during a flushing which was at a rate calculated to displace the water three times. No coliform organisms were found and the counts were mostly under 100. On the day following, during slow flushing, three samples were taken, all of which represented water held in the line for one day. Coliform organisms were absent in fifteen 10-ml. portions but the counts were considerably higher than on the day before. The water was left in the line for another day, this being a total of two days in the line and three days since the line was first filled with water. On sampling, coliform organisms were present in nine out of fifteen 10-ml. portions and the counts were above 1,000. At the last sampling, a month after the line was laid, the counts were around 20,000 and two coliform organisms were obtained from ten 10-ml. portions. This line is very little better than the poorest of the untreated lines.

Another line was laid with no treatment of the tubular-rubber packing or pipe. It was flushed when finished.

The line was chlorinated and allowed to stand for 48 hr. after which time the water in it contained more than 100 ppm. of free chlorine. After the chlorine was flushed out and no trace of residual remained, coliform organisms were absent and the count was one. Seventeen hours later the results were the same. Forty-nine hours after the chlorine was removed, one coliform organism was obtained and the count was just under 1,000. Counts increased to about 15,00 and coliform organisms were present in many 1-ml. portions in 10 days after chlorinating.

The line was re-chlorinated. Since all laboratory work seemed to show that the rubber did not contain coli-

form organisms, it appeared that they might be protected in some mysterious way in the pipe coating which is not wetted easily. In order to be sure that the chlorine solution came into contact thoroughly with the inside of the pipe, "Dreft" was fed uniformly with the chlorine solution.

After two days in the main, the water contained more than 100 ppm. of chlorine. At it was flushed into the gutter several inches of fine grained foam formed on the surface, giving evidence of a greatly lowered surface tension. Coating scraped from a pipe in storage was wetted in this solution and sank to the bottom at once. In plain water it tends to float.

During the first 48 hr. after the chlorinated water was removed, six 100-ml. portions yielded no gas formers and counts were normal. On the second day the counts were very slightly increased. Three days later counts were above 30,000 and coliform organisms were present in some of the 10-ml. portions. The counts fell almost as suddenly as they rose and ranged from 3,000 to 8,000 for the duration of the test, which was continued for 52 days after the last chlorination. From time to time the line was flushed with only temporary reduction in counts and these were by no means reduced to normal. For one period of eight days, coliform organisms disappeared even in 100-ml. amounts, but they reappeared and were present in nearly half of the 10-ml. portions thereafter for the duration of the test. The control sample, some 150 ft. from the start of the new line, yielded normal counts of two or three and no gas former was found, even in 100-ml. portions.

Where the gas formers, coliform organisms and high counts came from is hard to understand. Further exploration of the possibilities led to the examination of the pipe enamel.

Enamel was scraped from pipe in storage and treated with 100 ppm. of chlorine in water containing Dreft. After 24 hr. the chlorine was removed by rinsing and tap water was left on the enamel. A decided increase in bacteria occurred, the counts for the first three days being 120, 900 and 5,400. This experiment has been repeated three times over a period of four years with similar results, new samples of coating from old pipe being used in each case. Counts on water over enamel sterilized by autoclaving did not increase.

Experimental sections of 6-in. pipe were made up using (1) hemp, (2) lead wool, (3) Klerol swabbing, and (4) a non-ferrous pipe. The pipes were chlorinated in place, 150 ppm. of residual chlorine being present after 24 hr. of contact. Water was passed through them at controlled rates, usually to give a three-day retention, over a period of about two and a half years. The temperature varied from 69° to 79°F. Laboratory tests were made frequently to determine bacterial count, presence of coliform organisms, turbidity, alkalinity, pH, iron, dissolved oxygen, odor, nitrite and ammonia. Only small differences in these items were noted except as in the following cases:

Of the ferrous pipes, the one packed with hemp yielded the highest counts initially but not later. The non-ferrous pipe yielded counts materially lower than the rest but still averaged almost 10,000. No pipe yielded coliform organisms at any time.

The dissolved oxygen was reduced about 2.5 ppm. in the ferrous pipes and 1.5 ppm. in the non-ferrous.

In one period, after continuous flows were discontinued, the water was held in the pipes for 48 days at the end of which time that in the ferrous pipe had suffered a reduction in sulfate content of 5.2 ppm., while that in the non-ferrous pipe had gained a small amount of sulfate.

The water from the ferrous pipes generally had a tarry odor, intensified by prolonged storage in the pipes. The water in the non-ferrous pipe never developed that odor, even in more than a year of storage in the line.

This odor has been obtained in old dead ends in the distribution system where the possibility of its having come from the pipe lining is very remote—almost impossible. The odorous substance has been extracted from the water on several occasions with chloroform. It is seldom found in the winter and is always accompanied by high bacterial counts. Controlled laboratory experiments have not produced this odor with certainty, but it is believed to be of bacterial origin and to be formed only in the presence of iron and sulfur in some form.

The correct procedure which should be followed in laying new mains has not yet been developed. Common sense condemns the use of untreated hemp. Observation of main-laying operations shows that it is anything but a clean job. The men who must be employed on such work are anything but immaculate. Therefore all possible precautions should be taken.

Conclusions

The experiences recounted lead to the conclusion that:

1. The sterilization of mains in place can be accomplished with some uncertainty as they are laid at present.

2. Explosive growth of bacteria may come from seed in and on pipe lining rather than from sterilized packing material, either hemp or rubber.

3. A more offensive dead-end odor develops in ferrous than in non-ferrous lines.

4. The multiplication of bacteria occurs in both ferrous and non-ferrous lines but to a lesser extent in the non-ferrous lines.

Recommendations

It appears reasonable to suggest the following:

1. Use non-ferrous pipe or lining to improve odor and bacterial counts.

2. Use mechanical joints with rubber packing faced with lead.

3. Seal each length of pipe with tightly-fitting thimbles as soon as its manufacture is completed in order to keep out dust and dirt until the pipe end is ready to be put "home" into a joint in the trench.

4. Flush progressively and thoroughly from the junction with the old line at each hydrant in the new line.

5. Chlorination should maintain a residual of 50 ppm. for 24 hr. holding time in the line.

6. Sample the line daily for at least five days. If the results warrant it, rechlorinate.

Editor's Note: The need for disinfection of water mains after repair work is sharply indicated by the abstract on page 115, entitled, "An Epidemic of 3,000 Cases of Bacillary Dysentery Involving a War Industry and Members of the Armed Forces."

Bacteriology of Water Pipes

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Consultant, Los Angeles, Calif.

Presented on Oct. 26, 1944, at the California Section Meeting, Los Angeles, Calif.

BACTERIA are always present in water, even in the effluent from the most modern and efficiently operated treatment plant, in spite of the fact that the effluent may carry 0.2 or 0.3 ppm. residual chlorine as it enters the distribution system. As a check upon the effectiveness of treatment many plants inoculate agar culture plates which are incubated at 37°C. for 24 hr. to determine the "total count" of bacteria. Such plates often show no bacterial colonies at 24 hr., and generally the count does not exceed thirteen per milliliter, but the term "total count" is a misnomer, unless we add the qualifying phrase "on standard nutrient agar incubated at 37°C. for 24 hr." Incubating the same plates at 20° C. for 72 hr. produces many more colonies. Again, culturing on the same medium and for 72 hr. at 20°C., but in the absence of oxygen (anaerobic culture), will produce an abundant crop of different bacteria. Manifestly it is impossible to enumerate accurately *all* the bacteria present.

Such experiments prove that certain bacteria manifest themselves under particular conditions and not under others, and that many kinds are able to survive dosages of chlorine which will readily exterminate the colon bacillus and the organisms which cause typhoid fever, Asiatic cholera and the bacillary dysenteries. In other words, the kinds and numbers of bacteria which "thrive" in a given situation are dependent on the environment. Many bacteria which are unable to flourish in a particular environment are able to survive there in a dormant state for indefinite periods, and will multiply rapidly when the environment changes to a more favorable one. The pipes composing the distribution system afford constantly changing environments, and as a consequence the prevailing bacterial forms differ from place to place and from season to season.

The most important factor controlling growths of bacteria is the available food. Waters vary within wide limits in the kinds and quantities of food substances which they carry, and as a consequence the dominant bacteria which flourish in pipes and the luxuriance of their development are equally variable. In this connection ZoBell has done some interesting work to determine just how small an amount of organic matter in water is sufficient to support large bacterial populations. He found that *Escherichia coli* will multiply in water containing no organic matter other than 0.1 ppm. glucose, but that vigorous growths were not obtained unless glucose, unaccompanied by other organic substances, was present in concentrations ranging from 10 to 100 ppm.

Incidentally, he expresses a thought which all bacteriologists working on water would do well to take to heart

when he quotes a personal communication from Prof. E. G. Hastings as follows: "It has always seemed to me that we tend to grow micro-organisms in the laboratory under conditions which are vastly different from those existing in nature, and that therefore the viability and vitality of the organisms as we study them may be quite different from those in nature." (J. Bact., **45**: 555 (1943).)

It is safe to say there is no water supply in the world which does not contain sufficient food to support active bacterial growth. An impounded surface water which is allowed to produce abundant growths of algae and which is not filtered will contain great quantities of bacterial food in the bodies of algae which must quickly perish in the darkness of the pipes. Such waters cause the greatest troubles in the distribution system. Filtration will effectively remove solid foods, but not soluble ones, such as vegetable and animal extracts, nitrates, phosphates, sulfates, hydrogen sulfide and many others.

Most of the bacteria which inhabit water pipes are attached forms which build encrusting colonies or slimes over the walls of the pipe. As a consequence tap samples drawn from a pipe which is heavily infested with slimes may, and often do, yield low total counts, thus giving the unwary observer a false impression of sterility. To facilitate in the study of these attached forms one must resort to special technic. Some resourceful bacteriologist devised a scheme of installing a corporation cock on a main, to which he attaches a nipple about 6 in. long, closed at the outer end by a stuffing-box through which is inserted a rod, on the inner end of which is affixed a clamp to which is secured an ordinary glass microscope slide which has been sterilized. When this is in place in the nipple and the stuffing-box securely seated, the corporation cock is opened and the glass slip pushed into the pipe where it is left for a period, after which it is withdrawn for study. The results are enlightening, and most surprising to one who uses the method for the first time.

The pipe-dwelling organisms considered here will be limited to those which are the first to intrude themselves on the attention of the consumer, for they may affect the odor, taste, color and turbidity of water. They may also cause corrosion of pipes with the production of tubercles, and give rise to other and unexpected troubles, especially "red water."

Crenothrix

Of first importance, at least in southern California, is *Crenothrix,* sometimes spoken of as the "water calamity." At least two cities in California can ruefully testify to the aptness of the term, for it has been their "Enemy No. 1" for years. *Crenothrix* belongs among those bacteria which are termed "autotrophic," that is, those which can subsist on inorganic foods and which can utilize carbon only from carbonic acid, not from organic compounds such as carbohydrates. Moreover, they derive their energy only from the lower oxide carbonates of iron or manganese through a process of oxidation. This means they can flourish only in waters where such salts are present. In passing it is interesting to note that these particular compounds are present only in water which contains free carbon dioxide, which alone holds them in solution.

Properly speaking, one should not use the term "carbon dioxide" when

referring to that gas dissolved in water. To convey a correct picture of conditions in water pipes one should say "carbonic acid," for carbon dioxide when dissolved in water always behaves as though it had taken up the elements of water to form that acid, according to the equation:

$$CO_2 + H_2O = H_2CO_3$$

Realizing this, it is easy to understand how water which contains carbon dioxide has a depressed pH value and tends to be corrosive in character. But carbonic acid itself has never been isolated, and perhaps never can be, so it has to be determined by the chemist as carbon dioxide. Hence it has customarily been reported as such, or by some chemists as "carbonic anhydride," a term which immediately suggests its acid character.

Crenothrix is a normal inhabitant of soils, and it readily finds its way into water. Apparently it is always present in small numbers, and it probably exists in a resting stage comparable to hibernation, until conditions become favorable for its development, when it makes itself quite at home. Actually, the most important and critical factor in its development is carbonic acid, for when that is present it will attack the metal of the confining pipe with a resulting production of carbonate of iron and manganese. Naturally, the forms of life found to be active in any given locality—the "communities," to use a biological term—are determined by the environment. We all know that environment reacts upon an individual, be it man or bacterium, but we sometimes forget that it is also true that the individual exerts upon its environment an effect of equal amount, although different in character. Hence environments and populations change not only from place to place, but in the same place from time to time.

Crenothrix, except when migrating, is an attached form, tending to spread its colonies over the surface of the pipe. In order to understand how it is able to make so much trouble it is necessary to digress for a moment to consider some fundamentals of biology. First, in nature bacteria are never found in pure culture, but only in cosmopolitan mixtures (communities) of numerous forms, some of which may be in a dormant stage, due to unfavorable environment at the moment, yet ready to become active when the opportunity arises. What happens in a pipe, then, is the result of the activities of a mixed population, seldom, if ever, the performance of one specie.

Second, bacteria exhibit antagonisms as well as friendships, the latter being referred to more properly as "symbiosis," a word which means living together in harmony. For an example of the former, it may be stated that bacteria which produce hydrogen sulfide as a metabolic byproduct would antagonize *Crenothrix,* because the hydrogen sulfide would remove the iron, which is all-essential to *Crenothrix,* precipitating it as the insoluble iron sulfide. This has actually been observed in one of the tunnels of the Metropolitan Water District. Here *Crenothrix* flourished above the hydrogen sulfide area, but was completely dead and blackened within that area which had subsequently been invaded by sulfur-bearing ground water. An example of symbiosis is the ability of typical *Esch. coli* to flourish in water in the presence of cellulose which is being used by cellulose-splitting bacteria, one of the byproducts of whose metabolism is cellobiose, upon which colon bacillus can thrive. The jute so

commonly used for packing joints in water pipes is cellulose, and where persistent coliform findings have been traced to it we are dealing with symbiosis in a practical way. The most recent account of this phenomenon, and one reporting a most painstaking study, is to be found in a paper by J. R. Sanborn, of the New York State Experiment Station, entitled "Slime-producing Coliform and Coliform-like Bacteria" (J. Bact., **48**: 211 (1944)). This paper summarizes fiften years' work on slime-forming bacteria in contact with cellulose.

In it Sanborn says: "Out of 175 samples of slimes examined for coliform bacteria, 94 per cent yielded varieties of *Aerobacter* as the principal slime producers. Six per cent of the cultures isolated were more closely related to the genus *Escherichia* than to the genus *Aerobacter*."

Under our present bacterial standard for drinking water *Aerobacter* has the same sanitary significance as *Escherichia*, hence the importance to the water works profession of the association between cellulose-splitting bacteria and organisms of the coliform group is apparent.

Third, a word about environment. We think of the salt water environment or of the fresh water environment—that of the running stream, of a lake or of a pipe—but to understand happenings in a water main we must envision the micro-environment, or microsphere (the "world" of the bacterium), which may have one dimension only a few thousandths of a millimeter in extent.

I recently had the privilege of entering a 36-in. steel transmission line which had just been dewatered after two years of continuous service carrying lake water which had been stored for many months. The wall of the pipe was liberally sprinkled with strongly convex droplets of jelly, one or two millimeters in diameter, some slightly larger. They had a reddish tint, and could be readily slipped from place. Examined later in the laboratory they were found to consist of a mass of bacterial slime, in and through which ran filaments of *Crenothrix*. The lake water contained no iron or mangenese and only small amounts of carbonic acid, the pH ranging from 7.3 to 8.0, depending on season, depth of draft and abundance of phytoplankton. How could *Crenothrix*, which requires iron and manganese, live in such an environment? The answer is that within the globule of gelatinous material containing the bacteria, a micro-environment had been created which contrasted sharply with conditions in the stream of water flowing less than a millimeter distant. The jelly which held the colony attached to the pipe was saturated with water which was retained in a state of virtual stagnation, being replaced by new water only slowly, thus giving time for exhaustion of those dissolved constituents which the bacteria could use, and for loading up the water with soluble by-products of bacterial activity. As water reached the jelly it had an average pH of perhaps 7.5 and was not actively corrosive. The bacteria were producing carbonic acid, both as a by-product in the cleavage of food materials, and as the end result of cellular respiration. Accumulation of this acid in water of the microsphere depresses the pH below the neutral point, and the location of greatest acidity is next to the pipe wall, farthest away from the flowing water. Free carbonic acid in contact with bare iron and in the presence of water, results in corrosive

attack, the metal being taken into solution as ferrous bicarbonate, which can be utilized by *Crenothrix*. Thus by teamwork with slime-forming organisms, *Crenothrix* is able to flourish in a pipe carrying water which is iron-free, a seeming anomaly until the part played by symbiosis in creating specialized environments is understood.

In one instance where *Crenothrix* was a constant trouble-maker in the distribution system its control was attempted by the use of sodium carbonate. The water was derived from wells, and it contained small amounts of iron and manganese, as well as from 11 to 17 ppm. of free carbonic acid. It was believed that sodium carbonate, sufficient in amount to raise the pH to 8.0 or even 8.3, would neutralize most of the carbonic acid with precipitation of the iron and manganese, and so starve *Crenothrix* into submission. Such a treatment was decided upon because it was easily applied, inexpensive and promised material relief until such time as a conventional treatment plant could be built, and the degree of success attained warranted the innovation.

One incident in this campaign to control *Crenothrix* may be mentioned as a concrete illustration of the reality of microspheres. After sodium carbonate treatment had been continued for some time we found "white sand" was flushed from one of the mains. Examination showed the "sand" to be calcium carbonate öolites having a maximum dimension of a few tenths of a millimeter. Exhaustion of free carbonic acid in the capillary film surrounding the *Crenothrix* filament had caused reduction of calcium bicarbonate to the insoluble monocarbonate upon and around the filament and the process continued until the bacterial cells were killed. Other filaments in the skein twined over the buried one only to be coated in turn, and the process was repeated until the öolite was large enough to be washed from its anchorage. The carbonic acid content of the flowing water where the öolites were formed was 4 or 5 ppm., or sufficient to prevent the formation of normal carbonate except within the microsphere. Farther down the main, where these öolites were deposited upon bacterial slimes in the invert of the pipe they were redissolved by the excess carbonic acid in that localized environment, as was abundantly attested by the finding of partially dissolved öolites.

Beggiatoa

Bacteria of the sulfur cycle are always to be found in water pipes, where they may become active agents of corrosion. *Beggiatoa* is most widely known, for under favorable conditions it forms white filaments an inch or more long. I have seen them 8 to 10 in. long in sulfur water in the Owens Valley.

This bacterium obtains its energy from the oxidation of hydrogen sulfide, and, like *Crenothrix*, can use carbon only from carbonic acid. Elementary sulfur is produced as a by-product in the utilization of hydrogen sulfide, and it is stored up in the bacterial cells, giving the filaments a characteristic appearance which, coupled with a serpentine form of motility, renders them easily identifiable.

Beggiatoa is not a frequent cause of trouble in water pipes, as few domestic supplies contain hydrogen sulfide, but it is found in "dead ends" whenever there is a sufficient collection of organic matter to produce hydrogen sulfide. Nevertheless, it has caused

much trouble in several suburban areas of Los Angeles, but always in waters at the source, or where such waters were used untreated. It can be kept out of mains by aeration, filtration and the use of chlorine. It may be an indirect cause of corrosion when its stored sulfur is utilized by the next organism to be mentioned.

Thiobacillus Thiooxidans

Potentially the most important member of the sulfur cycle is *Thiobacillus thiooxidans*, which oxidizes elementary sulfur to sulfuric acid, thus obtaining energy with which to assimilate carbon from carbonic acid. Experimentally it attacks the sulfur-silica compound often used to calk the joints of cast-iron pipe, and since it is able to build up a concentration of sulfuric acid greater than tenth-normal, it could cause active corrosion if it gained access to such compounds. It may succeed a decadent growth of *Beggiatoa*, utilizing the sulfur which that organism produced as a byproduct. Such a growth would be transient, being limited by the amount of sulfur available, but in the meantime it could initiate corrosive processes which would continue after *thiooxidans* had disappeared.

Other organisms of the sulfur cycle of importance in water pipes are those which reduce sulfates. It will be remembered that all bacteria are divided into two classes with respect to their oxygen requirements. Some flourish only in the presence of atmospheric oxygen, hence are called "aerobic." Others flourish only in the absence of atmospheric oxygen, and are called "anaerobic." Of course there are intermediate forms, and some aerobes are able to adapt themselves for longer or shorter periods to anaerobic conditions. But no bacteria are able to live without oxygen, and the ones that can thrive in the absence of air can do so only because they have learned to pry loose oxygen from some of its compounds. In this respect they seem to be more fortunate than the modern aviator who must carry his oxygen with him when he invades the rarified atmosphere of the stratosphere. Both the bacterium and the aviator have found ways to overcome successfully an adverse environment, but it would seem the former has attained the more practical solution, for he takes his oxygen out of the adverse environment while the human has to carry his into enemy territory, thus being dependent upon his line of communications, a situation which does not apply to the microbe.

Many bacteria are able to reduce sulfates, salts which are seldom absent from water, with the release of the all-necessary oxygen and the production of hydrogen sulfide as a byproduct. When calcium sulfate is attacked the reactions are:

$$\underset{\text{calcium sulfate}}{CaSO_4} - \underset{\text{oxygen}}{4O} = \underset{\text{calcium sulfide}}{CaS}$$

$$\underset{\text{calcium sulfide}}{CaS} + \underset{\text{carbonic acid}}{H_2CO_3} = \underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{hydrogen sulfide}}{H_2S}$$

This form of bacterial activity occurs only too often in water pipes, and it causes vociferous complaints. Some years ago, the author had an opportunity to observe personally a most interesting case at Beverly Hills, Calif. At that time the city derived its water from wells most of which yielded sulfur water. After several years of endless trouble they built a modern and architecturally beautiful plant which produced an effluent that was free from

hydrogen sulfide and in all respects an acceptable and palatable water. But a few days later I was called to investigate an especially venomous complaint emanating from an attractive home in one of the better residential districts. The consumer explained she had just redecorated her home, and had her bathroom finished in spotless white, using the best white lead paint money could buy.

We found the walls a dingy brown to black where the fumes of hydrogen sulfide had converted the white lead to lead sulfide and we felt her complaint had been fully justified. Sulfate-reducing bacteria still rampant in the mains had produced as much hydrogen sulfide in the treated water as had been present before the plant had been built. A long campaign of chlorination and flushing of the mains was necessary before the trouble-makers were eliminated.

A more recent experience in which sulfate-reducers were responsible for serious corrosion occurred in cooling-water lines at the steel plant of the Timken Roller Bearing Co. in Canton, Ohio. Some of these lines had a life of only a few months. A detailed report of the trouble and its control through the use of chlorine has been made by Clark and Nungester in the Transactions of the American Society of Metallurgists for June 1943. Dr. Nungester, Associate Professor of Bacteriology in the University of Michigan, isolated the sulfate-reducers and proved their corrosive abilities in culture in the laboratory.

All of these experiences shed light upon the cyclic nature of life and the cyclic transformations of matter, especially of carbon, sulfur, iron, manganese and, we might add, nitrogen and phosphorous. They bring out the successions of micro-populations in response to changing environments, and also illustrate the co-operative work of bacteria in symbiotic association. They voice a challenge to bacteriologists for intensive investigation of the micro-populations of water pipes, not in pure culture, but as naturally growing communities of mixed bacteria, fungi and protozoa. The microscope slide culture method offers great opportunity for investigation, and the substitution of metal slips of the same size and thickness makes it possible to study the phenomena of biological corrosion and tuberculation. The opportunities for fruitful investigation opened up by this method cannot be neglected by those who are interested in the quality of water after it has entered the distribution system.

Water Conservation in Washington, D.C.

By Edwin A. Schmitt

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Presented on Nov. 10, 1944, at the Four States Section Meeting, Philadelphia, Pa.

THE conservation of water in the national capital has a double-barreled objective. One is to carry out the requirements of the War Production Board that all possible efforts be made to conserve the use of critical materials, such as fuels, power, chemicals, manpower and transportation. The second is to postpone, as far as possible, construction of additional facilities which would otherwise be required and thereby hold down expenditures.

Organization

Accordingly, there was set up by the Commissioners of the District of Columbia a Sub-committee for the Conservation of Water, which was a part of a very much larger committee composed of federal, District of Columbia and civic members, and entitled the Committee on the Conservation of Critical Resources, whose function is to conserve coal, petroleum products, transportation, gas, electricity, communications and water.

The sub-committee on water, set up in December 1943, is composed of:

Chairman
Director of Sanitary Engineering, District of Columbia

Vice-Chairman and part-time Acting Chairman
Head Engineer, U.S. Engineer Office, in charge of Washington Aqueduct System

Executive Secretary
Assistant Superintendent, District of Columbia Water Department, and Director, War Public Works Projects for District of Columbia

Member
Representative of U.S. Public Buildings Administration, handling housing and maintenance of federal establishments in the Washington area

Member
Chief Engineer, Arlington County Water Department, which receives its water from Washington

Participator
Superintendent, District of Columbia Water Department, which administers distribution system

Participator
Superintendent, Washington Aqueduct System, which encompasses supply division

Lines of Endeavor

The sub-committee laid out a broad program of conservation of water in every direction possible. The problem was attacked along both internal and external lines. This included the check-up of use practices, waste and physical leaks by each of the two divisions of the water system, viz., the Water Department of the District of Columbia and the Washington Aqueduct System. In addition, the federal departments, industrial establishments, commercial houses and private parties were solicited along the same lines directly and by the media of newspaper publicity, folder inclosures with mail, individual letters, etc,

The various departments of the municipal government were circularized on the conservation of water and the reporting of leaks and waste. Similar action was taken within the U.S. Engineer Office organization, especially on the Washington Aqueduct supply system. The Public Buildings Administration representative on the sub-committee also instituted a conservation campaign through the medium of 6,000 circular letters and Arlington County followed suit.

The 98-page handbook of the American Water Works Association on "Water Conservation," which outlines a voluntary and selective program to aid water utilities in a co-operative "Stop Water Waste" campaign, was highly useful in laying out the conservation program and in scheduling the follow-up activities.

Publicity

The Commissioners of the District of Columbia issued a proclamation which read as follows:

Whereas, the full prosecution of the war effort requires enormous supplies of arms, ammunition, ships, fuel, food, medical supplies and equipment for our own and our Allies' use, and

Whereas, to provide ample and continuous supply of these essential materials requires sacrifice and self denial on the part of the civilian population of our country in the use of these critically needed supplies, and

Whereas, the United States War Production Board has inaugurated a broad conservation program to effect savings in critical resources, namely manpower, material, equipment and fuel; by reducing domestic, commercial and industrial use of coal, petroleum products, electricity, gas, water, communications and transportation,

Now, therefore, we, the Commissioners of the District of Columbia, having full faith and confidence in the will and determination of the citizens and residents of the District of Columbia to co-operate in performing the voluntary economies requested by our Government, do hereby proclaim that beginning October 1, 1943, until further notice from our Government, it is considered in the national interest that all coal, petroleum products, electricity, gas, water, communications and transportation users residing or doing business in the District of Columbia, voluntarily conserve such use in every prudent manner.

The aid of the general public and commercial concerns was invoked through news items in the daily papers. Garden editors in their weekly columns gave advice on how to get along with the minimum use of water for gardens and lawns and urged that such use as was necessary be made during off-peak hours. A news item box on water conservation was carried monthly in the *Board of Trade* publication.

The *Washington Evening Star* newspaper, with a daily circulation of 200,000 copies, was so impressed with the conservation effort that one of its editors prepared an editorial on the subject. For clarity and simple straightforward presentation, avoiding any scarehead elements, this publicity was excellent and merits repetition here.

DO NOT WASTE WATER

The District's water supply is plentiful enough, for the minimum flow of the Potomac, even in times of relative drought, is adequate to meet Washington's maximum demands. Improvements in the supply system have increased the production capacity of filtered water, and even with such a record day's consumption—197,900,000 gal. —as there was on Tuesday, the supply system is able to keep up. How long such peak loads could be sustained, however, without drawing too heavily on the reserves—which amount to less than a day's supply on the whole—is another question. The welcome rain of the past twenty-four hours will reduce—even if only temporarily—the city's tremendous thirst. There are other reasons than production capacity, however, which enter into the need for conservation. The supply of chemicals and other materials used

in purifying water, and their transportation, take away just so much from the Nation's war production facilities. Every effort is being made not to tax them by wasteful use of water. Back in 1928 it was unlawful to sprinkle lawns or wash down the streets except during certain hours. Such prohibitions have not been necessary in recent years. By careful use of water, they can be avoided.

Radio was not used for publicity purposes as for the time being it is planned to utilize this medium only for emergencies or when a critical situation arises.

Since there were no general funds that could be drawn upon to bear the expense of sending out printed matter, it was necessary to concentrate on a single widespread effort of this nature, requiring only a moderate expenditure. The sticker illustrated in the figure was prepared. About 6,000 were distributed for pasting up wherever extensive use of water occurred and especially in wash rooms. The main effort, however, was the inclosure of the sticker with the May bills of the electric utility, the Potomac Electric Power Co. A total of 227,000 was thus placed in the hands of the general public and business establishments. In addition these stickers were inclosed with the Water Registrar's correspondence in the District of Columbia and with the water bills in Arlington County, Va. Real estate agents asked for some 2,500 additional stickers to give to tenants of their properties.

Individual letters setting forth the means whereby water could be conserved were written to many organizations. Among these were the Citizens Association, 58 letters; civic associations, 22 letters; trade organizations, such as hotels, laundries, restaurants, manufacturers, building associations, utility companies, and large users; federal agencies, 24 letters.

Physical Aspects

The attack on the visible and physical sources of water use took many different directions and also resulted in a rejuvenation of existing practices which for lack of necessity had not been so actively pursued in recent times. First to secure attention were the public display fountains and then in order came the check of automatic flushing, abandoned services, air-conditioning, street flushing, etc. The District Water Department, with funds made available, resumed its pitometer surveys, to locate leaks or waste in its distribution system. This resurvey, however, is only 10 per cent completed at this date. Another step by the District Water Department was an accelerated program of meter inspections and repair which was made possible with additional funds becoming available for the purpose. Wartime restrictions have prevented accomplishment of the desired meter rehabilitation program, but a very substantial amount of meter work is being completed this year. The Washington Aqueduct System instituted a special program of inspecting hydraulic valves, glands on pumps, use of bearing cooling water, transmission mains for waste and leakage, and surveyed its reservoirs to ascertain if there existed undue leakage. Arlington County scheduled night flow tests to detect possible distribution system leakage.

A method of securing notice of leaks was instituted whereby the inspectors of the health department and building inspector's offices in their tour of duty reported all observable leaks. For this the following form was used:

WATCH WATER WASTE

Water is being needlessly lost as indicated below:

1. Leaking sink faucets............ ....
2. Leaking bath faucets............ ....
3. Leaking lavatory faucets........ ....
4. Leaking water closets........... ....
5. Leaking hose bibs.............. ....
6. Leaking piping................. ....
7. Leaking hot water tank......... ....
8. Other evidence of leaks.......... ....

Please have necessary repairs made right away! Many critical resources, vital for war needs, are required to produce the water to use so—SAVE ALL YOU CAN. It will help the war effort and may save you money too.

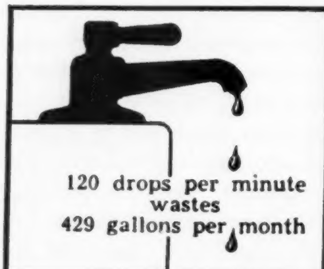
Premises ....

The water department thereupon investigated the reported trouble and instituted measures for corrective action. A carbon copy of the check-list was left with the occupant of the premises. The reverse side of the check-list showed the quantity of water wasted by different sized leaks.

In addition, the police department submitted daily reports of leaks or other special water conditions observed by its patrolmen and these conditions were similarly investigated. These various reporting measures, while efficacious, have only been in force for a short period of time so that the full results are not yet evident.

Response to Campaign

The responses to these various appeals for the conservation of water were most encouraging. The public reaction was reflected in an indirect way, some of which was quite amusing. Husband and wife have been overheard arguing about which one was wasting water. Numerous reports of leaks were received. Some federal agencies switched over from non-recirculating air-conditioning systems to closed system cooling. Utilities and other larger consumers made surveys of their heating and power



STOP WASTE
CUT "EXCESS" BILLS

USE WATER WISELY

Don't let water fixtures leak—
whether it be a Drip or a Deluge

Stop wasteful habits—
such as letting water run unattended

Use what you need when you need it, then—
TURN IT OFF

Water is a manufactured product. The electricity, chemicals, fuel, other critical resources and manpower required for its purification and distribution must be conserved for vital war uses.

COMMISSIONERS' COMMITTEE ON CONSERVATION OF CRITICAL RESOURCES
SUB-COMMITTEE ON WATER

plants. One of these surveys disclosed condensate being run to waste in considerable quantities. Corrective action not only saved water but fuel as well. Arlington County restricted the watering of lawns. Out of 3,500 abandoned services, 915 were checked and quite a number of persisting leaks were eliminated, but this work did not cover a full year.

Several anonymous communications enlivened an otherwise rather prosaic campaign. One signed "A Nobody Old Maid" was as follows:

Dear Sirs—How come?—We are warned to *not waste* water? No fountains running again this summer, very little watering of public parks,—yet *hundreds of thousands of gallons wasted by huge water wagons flushing sts.,* even Sousa Bridge? Our st. washed twice in one day recently, several times since, even tho it is swept 2 or 3 times weekly. Sewers must be flushed occasionally, of course; but that does not take anywhere near the *great wastage of water* merely watering sts. Also,—can't your Dept. *clamp down* on Fed. Govt. offices flushing sidewalks every morning, sometimes oftener? Places where grass is *three ft.* high, in front of such offices, around three in pavement,—because they have had all that water? Filling stations are in this class also.

Looks like the Water Dept. and St. Cleaning Dept. should cooperate in use of water, also all public and pvt. places. I'm only a Nobody Old Maid, no matter who.

While the conclusions are those of a layman unacquainted with the reasons or correct facts, yet the implications and the interest shown were such that the sub-committee took steps to secure such corrective action on the matters mentioned in the communication as were deemed feasible.

Another communication worth repeating was as follows:

How come sixth street gets watered every night? And I mean *every night,* even when it's pouring rain! Will you kindly tell the damn fool who's behind it to lay off. If he wants to be generous with the city's water, tell him to go water the river. It's been looking pretty dry. We got enough!

This caused the sub-committee to consider such use of water. Since restriction of critical materials had already curtailed the use of street flushing equipment so the water use was reduced from 600,000 gpd. to 375,000 gpd., the health department was of the opinion that for health and sanitary reason the program should not be further reduced until the situation became more critical.

Quite a few public responses partook of the tattle-tale and sniping character, which had to be handled diplomatically. In one case a tenant was able to secure the replacement of an inoperative hot water boiler which had nothing to do with the conservation of water.

General Data

To evaluate the results of the conservation program, some basic considerations must be presented.

According to recent informal estimates of the Census Bureau, Washington is the eighth largest city in the United States, and by reason of the territory supplied with water, the supply system takes on a metropolitan district aspect, because, in addition to the District of Columbia, all of Arlington County, Va., and a limited area in Maryland are served. The population thus supplied was, in 1940, according to the Census, 720,000. In the fiscal year ending in 1941, the population was estimated to be 773,000; in 1942, 855,000; in 1943, 913,500; and this year (1944), 996,000. The present population (November 1944) is estimated at 1,021,000. The

famous Pentagon Building, which alone has a working population of over 30,000 persons, is located in Arlington County. The government worker population reached a peak of 285,000 persons in 1943 and, while it is somewhat less today, little decrease in the over-all population is evident.

During the past summer, for instance, large numbers of college and high school students, as well as teachers, were employed by the federal government. Many have not resumed their studies. The size of the military population is one of great uncertainty. Whether located in the District of Columbia or in the Virginia environs, it secures its water from the Washington water system. While some military units have been deactivated, many others have experienced considerable growth as in the case of the WAVE, WAC, SPARS, and Marine Corps Women's organizations of the armed forces.

All of the civilian war agencies experienced many changes in personnel with the fluctuation of the war effort. While some have decreased, others have grown tremendously. With the continuance of war activities now for three years at the seat of the government, there also has been a noticeable change in character and habits of that population, both civilian and military, as, for instance, from crowded downtown quarters to residential areas.

If the population has increased, a saving has been accomplished, but there is no yardstick whereby this is measured. While there has been a decrease of 9,600 federal workers from July 1943 to July 1944, there is no means of ascertaining that the ratio of the supporting population (service functions, etc.) to federal workers has not replaced the federal workers loss or even that the ratio of the supporting population to the federal worker has increased. An attempt to estimate the population by a B.O.D. equivalent was made but the variables not only in character but in the amount of sewage treated were such that this method had to be abandoned.

The water consumption in the national capital and environs experienced a tremendous growth by reason of the centralization of war activities at the seat of the government. Some measure of this is evident from the tabulation below:

Fiscal Year Ending June	*Average*		*Maximum*	
	mgd.	*gal. per capita*	*mgd.*	*gal. per capita*
1941	113.8	147	159.2	194
1942	123.3	140	157.8	187
1943	129.9	142	185.8	194
1944	141.1	141	188.8*	196

* Maximum day, July 11, 1944—200.17 mgd.

Results of Conservation Campaign

The constant change that the population of the nation's capital is undergoing makes difficult the evaluation of savings in water from the above figures on consumption. To arrive at some idea of conservation accomplishments, two means were available for analysis. One of these was centered on specific surveys and corrective measures, and the other was the response of public agencies and the general public.

Since no definite figure for population growth subsequent to the census of 1940 is available as a measure of conservation results, recourse must be had to other means for establishing water savings. Of the varied efforts made toward conservation, those listed in the following table have been identified and in the main measured:

	mgd.	*Estimated Total mil. gal. for Year*
Abandoned services	0.049	17.885
Visible leaks	0.480	175.200
Invisible system leaks	0.260	94.900
Pitometer surveys	0.907	331.055
Horse troughs	0.263	95.995
Fountains	0.319	47.938
Automatic flushers	0.300	109.500
Street flushing reduced	0.225	33.750
Leaks corrected through check-list report (estimate)	0.090	3.285
Air-conditioning (changeover to re-circulating)	0.156	33.450
Corrective measures on meters and metering—		
a. Defective	0.415	151.475
b. Leaks	0.483	48.300
Survey of heating systems	0.100	18.000
Totals	4.047	1,160.733

It is considered that conservation of water in a much greater degree than the above positive measured savings has been effected. Practically every consumer was made to some extent "conservation conscious" and without question heeded some of the admonitions about leakage and waste. An estimate of the unrecorded water savings that resulted from the correction of leaking facilities, reduction of lawn and victory garden sprinkling, voluntary rationing, etc., is conservatively placed at 9 mgd. This is based on general observation, comments received as a result of the publicity, and the concerted effort of federal establishments and other large users.

Summary

With a minimum of expenditures there has been secured an estimated saving of 4,445 mil.gal. per year.

There has been caused a public awakening with respect to needless use of water and the expense of leakage.

The results attained have led to a proposal to continue not only during the war period, but on a permanent basis thereafter, the work of the sub-committee on the Conservation of Water to maintain not only the gains that have been secured, but to strive for even greater water savings.

The efforts of the sub-committee have stimulated and encouraged the continuance of efforts for better operating practices. In the distribution division of the water system this is toward additional and continued leak surveys and meter rehabilitation. In the supply branch a more concerted effort is being made toward the positive increase of about 30 to 40 mgd. in sustained capacity above the previous rated capacity, at only a fraction of the cost of providing equivalent capacity through new construction. Thereby present low operating costs will be maintained.

New major construction will undoubtedly be required in the near future so that it is reasonable to expect that rates for water delivered to the consumer cannot remain the same. Meanwhile conservation will help to hold the water rates at the present low level.

All in all, the conservation campaign has been interesting and most fruitful, and the ground work has been laid to continue this beneficial work in the future.

Water Conservation in Philadelphia

By Martin J. McLaughlin

Chief, Bur. of Water, Philadelphia, Pa.

Presented on Nov. 10, 1944, at the Four States Section Meeting, Philadelphia, Pa.

A REPORT of the Water Conservation Program of the Philadelphia Metropolitan Area for the years 1941–1943 appeared in the April 1944 issue of the JOURNAL. At that time the mayor had appointed a committee for the year 1944 on the Conservation of Critical Resources and the Philadelphia Bureau of Water carried out the following program:

(1) The pitometer leak and waste survey, including inspections and repairs was continued. To date the survey has discovered 30 mgd. with 90 per cent of the survey completed (Table 1).

(2) Pressures were regulated to prevent excessive waste of water.

(3) Routine hydrant inspections were made every quarter instead of semi-annually.

(4) Police supervision was exercised on hydrant usage.

(5) The water bureau supervised water usage for victory gardens.

(6) During the year the Bureau continued to call to the attention of the consumers, through the newspapers, the importance of the continued saving of water so that a shortage would not occur.

During the past summer in Philadelphia there were 31 continuous days of 90° temperature or over. The maximum day for 1944 occurred on July 12 when 387.4 gal. were consumed. The average of the maximum days for the first nine months was 353.1 gal. The average daily consumption for two-thirds of the year was 328.4 gal. All these figures are based on supply to the distribution system.

Figures alone do not represent the true saving because they do not reflect the tremendous demands for more water during the war emergency period due to increased war industries, war housing and war employment.

Essential water requirements each year have been increasing rather than diminishing. For example, it is estimated that the industrial demand for water in Philadelphia is now 25 per cent greater than it was in 1941 and that the influx of war workers has brought an additional 250,000 water users into the city.

Under normal conditions of water use, this would result in 45 mgd. greater demand. A total of 375 mgd. during the month of June would thus have been required. However, the stoppage of leaks and the termination of wasteful practices, such as excessive lawn and garden sprinkling, street showers and the like actually resulted in the decrease indicated.

If these results illustrate that the "habit" of water-watchfulness, of water-consciousness, has been acquired by the citizens in the Philadelphia Metropolitan District, they are more

TABLE 1
Philadelphia Bureau of Water
Water Waste and Leakage Survey
1940–1945

District Location	Section	Date of Contract	Work Started	Work Completed	Pitometer Co. Fee	Labor Used	Valves Checked and Repaired	Valves Checked
West Philadelphia	I	June 8, 1940	June 11, 1940	Feb. 22, 1941	**$32,000**	WPA	76 Restem 101 Repack 177	1,750
South and Central Philadelphia	II, III	June 4, 1941	June 15, 1941	Oct. 17, 1942	**$62,500**	WPA	83 Replace 34 Bonnet 1,000 Restem 1,064 Repack 2,181	4,037
Northeast Philadelphia (Kensington)	V	May 11, 1942	July 11, 1942	Apr. 15, 1943	**$24,000**	WPA	21 Replace 14 Bonnet 238 Restem 585 Repack 858	1,842
North Central Philadelphia (Logan)	IV A	May 25, 1943	May 24, 1943	Apr. 1, 1944	**$45,000**	Bureau of Water	2 Replace 12 Bonnet 258 Restem 178 Repack 450	2,069
North Central Philadelphia (Nicetown)	IV B	July 29, 1944	Mar. 7, 1944	90% as of Oct. 20, 1944	**$15,000**	Bureau of Water	82 Restem 63 Repack 145	758
Northeast Philadelphia (Frankford, Holmesburg and Torresdale)	VI	July 29, 1944	May 8, 1944	30% as of Oct. 20, 1944	**$35,000**	Bureau of Water	1 Bonnet 41 Restem 101 Repack 143	345
Northwest Philadelphia (Germantown, Roxborough and Manayunk)	VII				**Estimated Cost ($32,000)**			
Total—as of Oct. 20, 1944	6(—) Sections			as of Oct. 20, 1944	**$213,500**		106 Replace 61 Bonnet 1,695 Restem 2,092 Repack 3,954	10,801
Grand Total—as of Dec. 31, 1944					**Estimated Cost $245,000**			

TABLE 1—*Continued*

District Location	Broken Mains		Joint Leaks		Abandoned Services		Service Leaks		Miscellaneous Leaks		Abandoned Services Temp. Repaired by Shutting off at Curb		Leaks Located but not Dug up		Total no. of Leaks	Total Potential Leakage *gpd.*	Meters Under-Registering		Grand Total Leakage *gpd.*
	No.	Leakage *gpd.*	No.	Leakage *gpd.*	No.	Leakage *gpd.*	No.	Leakage *gpd.*	No.	Leakage *gpd.*	No.	Leakage *gpd.*	No.	Leakage *gpd.*			No.	*gpd.*	
West Philadelphia	11	781,000	6	60,000	25	503,000	154	1,418,000	6	146,000					202	2,908,000	13	2,502,000	5,410,000
South and Central Philadelphia	31	4,091,000	33	1,510,000	180	1,720,000	246	1,580,000	6	141,000					496	9,042,000	22	922,000	9,964,000
Northeast Philadelphia (Kensington)	6	612,000	20	504,000	73	1,325,000	54	574,000	2	45,000					155	3,060,000	5	784,000	3,844,000
North Central Philadelphia (Logan)	16	1,326,000	25	693,000	146	3,351,000	139	1,767,000	5	146,000	63	945,000	15	193,000	409	8,421,000	16	475,000	8,896,000
North Central Philadelphia (Nicetown)					14	198,000	35	347,000							49	545,000	1	100,000	645,000
Northeast Philadelphia (Frankford, Holmesburg and Torresdale)					1	21,000	11	92,000							12	113,000	1	427,000	540,000
Northwest Philadelphia (Germantown, Roxborough and Manayunk)																			
Total—as of Oct. 20, 1944	64	6,810,000	84	2,767,000	439	7,118,000	639	5,778,000	19	478,000	63	945,000	15	193,000	1,323	24,089,000	58	5,210,000	29,299,000
Grand Total—as of Dec. 31, 1944																			

Average Cost of Supplying Water to Consumer (1944 Rate)	$26.51 per mil.gal.
Total Water Saved by Survey as of Oct. 20, 1944	30,000,000 gpd.
Total Saving per Day	$795.30
Total Saving per Year	$290,284.50
Total Cost of Survey to Date	$213,500.00
Net Saving for Year 1944 Over Total Cost of Survey	$ 76,784.50

When Present Contract is Completed the Survey Will Cover 80 Per Cent of the System.

than acceptable. If they portend only an immediate response to a public service campaign on water conservation they should be viewed merely as a *hopeful warning*.

Wasteful water practices reach their most severe effects during July and August when the demands for water for home usage reach their highest yearly peaks; when industrial use of water for war purposes will rapidly rise; and when the burden placed upon the water supply filtration and distribution systems of the operating companies is greatest.

The practice of thrifty water use by each citizen *must go on* if an increasingly severe strain on the water supply systems of the Philadelphia Metropolitan District is to be avoided, with all of the risks attendant upon breakdowns in mechanical equipment, and resultant inadequacies in water supply for wartime purposes and the protection of public health.

The cost of the water conservation program in the Philadelphia Metropolitan District did not exceed $5,000, exclusive of the personal services involved, which were absorbed by the sponsoring and directing organizations. No additional personnel was employed for this campaign. The printing of posters, window cards, and leaflets was the only item of major expense. The city of Philadelphia was responsible for the cost of all material used within the city. The printing costs of the literature and poster displays used in the outlying four counties were underwritten by the major water companies servicing those areas.

Without such conservation efforts, the city of Philadelphia could not possibly meet the great demands placed on its system during the emergency.

Foot Valves on Centrifugal Pumps

By Robert W. Angus

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Presented on Apr. 21, 1944, at the Canadian Section Meeting, Niagara Falls, Can.

WHILE making some tests on a 4-in. single-entry, single-stage centrifugal pump recently, the author noticed that the pump was not giving its rated discharge and examined the suction conditions as a possible cause.

The pump has a foot valve of a relatively cheap type but one commonly sold for this purpose (Fig. 1). The opening through the seat is only $3\frac{11}{16}$ in. in diameter, as shown, and the flap valve is made of a piece of ordinary leather $\frac{1}{4}$ in. thick, to which is attached an iron disc $4\frac{11}{16}$ in. in diameter and $\frac{1}{4}$ in. thick. Although this leather has been in water for months, it is in good shape but is somewhat stiff. The openings in the strainer consist of 65 holes of $\frac{5}{16}$-in. diameter and 22 slots $1\frac{1}{8}$ in. × $\frac{5}{16}$ in. These were smoothed out a little before the tests were made.

In the test, the strainer was well below the surface of the well, but suction gage readings were made on a mercury manometer attached to the 4-in. suction pipe 13 in. above the well level. This connection was 15.5 in. below the center line of the pump.

Figure 2 shows the results of a careful test on the pump with the foot valve and strainer in use and with the leather seat and everything below it removed. The loss in the 2-ft. length of suction pipe is very small and the suction gage reading in Fig. 3 includes the 13-in. elevation, the velocity head in the pipe and the losses in the pipe, foot valve and strainer. These losses are almost unbelievably large. The suction gage reading is 16.5 ft. at a pipe velocity of 10 fps. At the rated pump discharge, the pipe velocity is 8.5 fps. and the suction gage reading is 13.1 ft.

That the suction losses affected the output of the pump is clearly indicated by the tests shown in Fig. 2. The author does not claim anything special for the pump, but it is a well-made one and gives good efficiency under medium suction lifts. Some pumps would not be much, if any, affected by the suction lift noted here.

Suction readings were then taken on a 3-in. high-lift pump on which the suction pipe has the foot valve and strainer, shown on the left of Fig. 1. The suction pipe consists of 6 ft. of 3-in. pipe with a long-radius, 90-deg. screwed elbow 8 in. from the pump flange. Details of the strainer and valve are shown, and the suction gage was on the pump flange, but its readings were corrected to the center line of the pump which was 7 in. above the gage connection, while the latter was 3.67 ft. above the well.

Readings on this suction gage were:

Pipe Velocity, *fps.*	5	6	8	10	12
Gage Reading, *ft.*	5	6	7.4	9.1	11.4

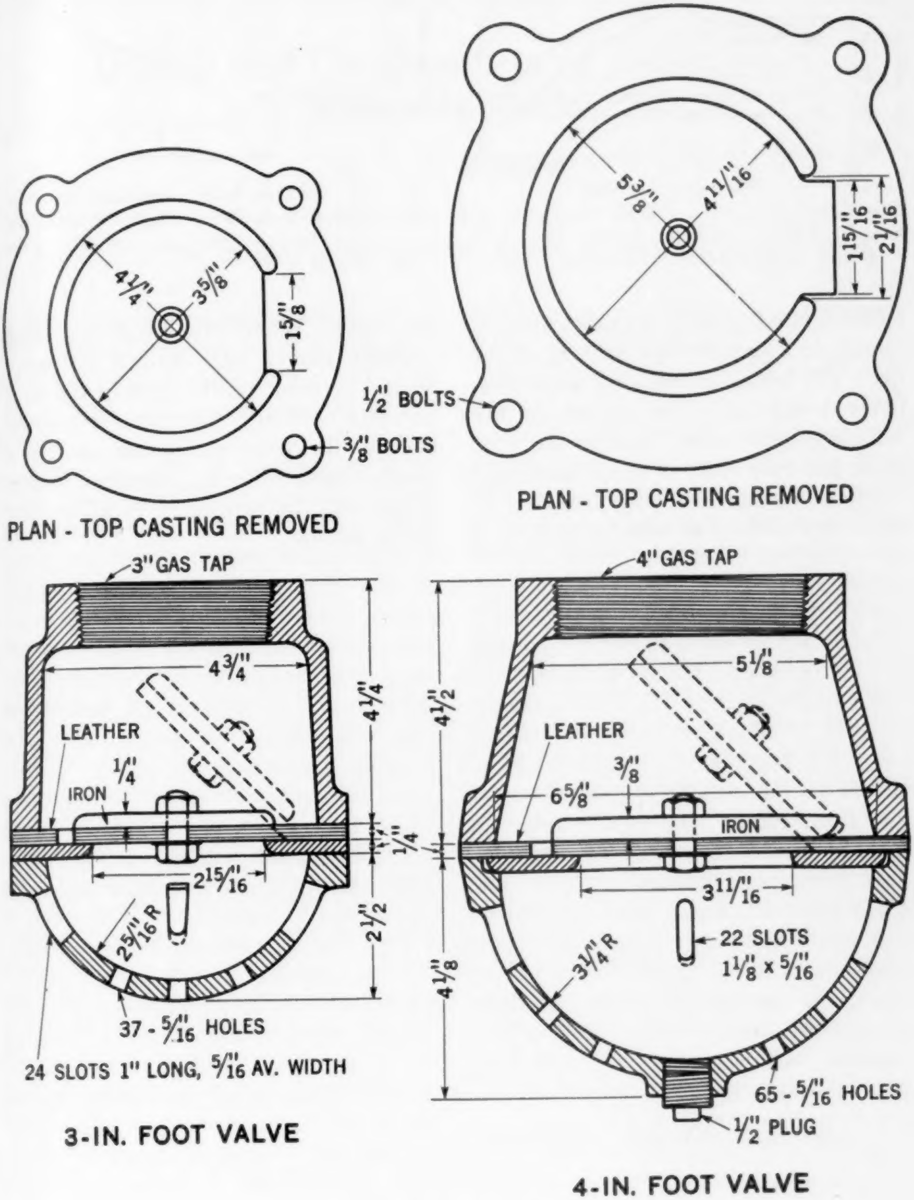
PLAN - TOP CASTING REMOVED
4 1/4"
3 5/8"
1 5/8"
3/8" BOLTS
3" GAS TAP
4 3/4"
4 1/4"
LEATHER
IRON
1/4"
1/4"
2 15/16"
2 5/16" R
2 1/2"
37 - 5/16" HOLES
24 SLOTS 1" LONG, 5/16 AV. WIDTH
3-IN. FOOT VALVE
PLAN - TOP CASTING REMOVED
5 3/8"
4 11/16"
1 15/16"
2 1/16"
1/2" BOLTS
4" GAS TAP
5 1/8"
4 1/2
LEATHER
3/8"
6 5/8"
IRON
3 11/16"
22 SLOTS
1 1/8" x 5/16"
3 1/4" R
4 1/8"
65 - 5/16" HOLES
1/2" PLUG
4-IN. FOOT VALVE

FIGURE 1

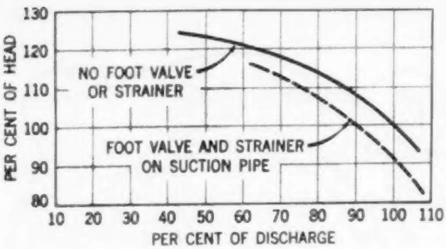

Fig. 2. Effect of Suction Losses on Output of 4-in. Single-Entry Low-Head Pump

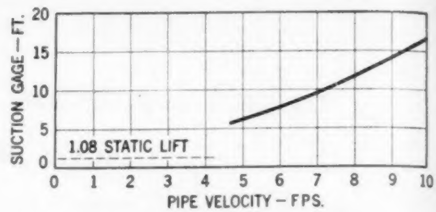

Fig. 3. Suction Gage Readings on 4-in. Single-Entry Low-Head Pump With Foot Valve and Strainer on Gage on 4-in. Pipe 13 in. Above Well

The rated pump capacity corresponds to a suction pipe velocity of 9.4 fps. The losses in this case were relatively lower and the leather in the valve appeared softer than in the 4-in. valve but they were of equal thickness.

These results are only intended to show how serious an effect a foot valve may have. Where possible it should be omitted and a bell mouth entrance should be made on the inlet of the suction pipe; priming may then be done by such a device as an ejector, or by a small motor-driven vacuum pump which may be connected to all pumps in the station.

Design and Construction of Prestressed Concrete Tanks

By R. C. Kennedy

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Presented on Oct. 25, 1944, at the California Section Meeting, Los Angeles, Calif.

ONE of the outstanding developments of recent years in the field of water works engineering has been the prestressed concrete tank or reservoir.

The basic idea of prestressing is to place the walls of a circular vessel under sufficient compression by tightening of bands before filling with a liquid, so that when filled there will be no tensile stress in the vessel walls. By so doing, the vertical cracks that would form at joints and at other locations due to tension are prevented, with the result that leaks and unsightly stains are avoided. This is precisely what has been done for centuries in the case of wood-stave tanks and wooden barrels, the swelling of the wood when wet being in these cases a factor in the tightening of the bands.

The earliest record that the author has found of the prestressing of cylindrical *concrete* structures is a patent issued to C. R. Steiner in 1908. Steiner's principal object as stated in his patent claims was to avoid the shrinkage cracks that would otherwise occur as the concrete hardened. In 1914 a patent was issued to George Rae, covering the banding of a cylindrical concrete structure by means of a continuous spiral wire wound on under tension, and placing it under high temperature was suggested as a means of creating additional tension as the metal cooled and contracted.

The idea of placing the tank sidewall on a flat foundation slab so that it could slide thereon, and filling the annular space between wall and floor with a mastic material, was patented in 1915 by M. Mueser. In 1922, William S. Hewett secured a patent on the coating of round prestressed bands with cement mortar as a protection against corrosion and to form additional bearing for the bands against the vessel's walls. To the author, the important contribution made by Hewett in this field appears to have been his very effective efforts in the education of water works men to the great advantages of the prestressed concrete tank over the massive, expensive and frequently leaky concrete structures generally used theretofore, and the development of many practical features in design and construction. As a result, prestressed concrete tanks are popularly known as "Hewett tanks," and the credit is well deserved.

Advantages and Disadvantages

With due recognition of the importance of other types of tanks, which, because of various inherent features, are in many situations the only practicable solution of storage problems, the following may be stated as the char-

acteristics of prestressed concrete tanks that have gained popularity for this type of construction:

1. High degree of water-tightness.
2. Permanence, with low cost for upkeep.
3. Adaptation to architectural treatment.
4. Adaptation to partial or complete burial underground.
5. Simple and accurate determinacy of stresses.
6. If properly constructed, high degree of resistance to damage from earthquake action.
7. Minimum of critical materials involved.

On the other hand, the principal undesirable characteristics of prestressed concrete tanks are:

1. Relatively high first-cost as compared with wood or steel tanks.
2. Impossibility of removal to another site if desired.
3. Relatively great weight to support if tank is to be of elevated type.

In many localities, as in the case of the East Bay cities, rugged topography makes storage facilities necessary in residential areas. The adaptability of the concrete structure to being partially or entirely covered with earth makes this type of reservoir acceptable where other types might engender great resistance from the neighboring property owners. However, even where the structure must be placed above ground, it can be treated architecturally to fit into the most fastidious residential surroundings. Where tastes run to the modern in design, little needs to be done other than to follow structural requirements. To date the district has not encountered

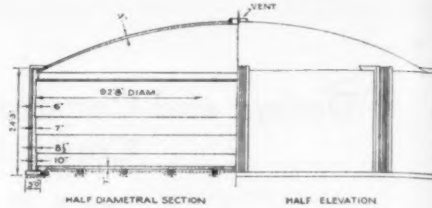

FIG. 1. Half Section, Half Elevation of 1-mil.gal. Reservoir

any serious resistance to the use of these tanks in any area.

Few engineering structures lend themselves to so accurate a determination of stresses as does the concrete tank, prestressed (Fig. 1). The freedom of the floor slab to expand and contract independently of the foundation ring obviates or greatly decreases the cracks that would occur in a restrained slab. With proper division of the slab into separate units of moderate size, cracking will not occur.

The tank walls are entirely free to "breathe" with changes in internal pressure, but if the joint with the floor is properly designed to permit such action, no disturbance of the water-tightness can result.

The great stability of the tank as a whole makes possible an unequal earthfill against its walls, but particularly in large-diameter tanks the danger of distortion makes such practice hazardous unless the local stresses in the walls are carefully analyzed and proven to be within safe limits. The accompanying photograph (Fig. 2) of the district's Montclair tank, 93 ft. in diameter and 33.5 ft. high, illustrates, however, what can be done in this direction. The convenience of such practice in hillside construction is obvious.

The cylindrical shape of a prestressed tank renders it essentially stable against the lateral forces resulting from earthquake action, but only if proper

attention is devoted to the development of tangential shear between the foundation ring and the walls. Radial grooves for this purpose are utilized by the district, and are described herein.

Because of the advantages of this type of structure, the East Bay Municipal Utility District has already constructed twelve prestressed tanks. The largest has a 3.5 mil.gal. capacity and is 160 ft. in diameter; three others are 130 ft. in diameter and have a capacity of 3 mil.gal. each. The remaining tanks range from 1.5 mil.gal. down to 200,000 gal. All have proven to be completely successful, and all that have been built by the improved methods described hereinafter are bottle-tight. The district's postwar plans include the construction of additional prestressed tanks with a total capacity of 12 mil.gal.

Typical Structural Details

In the construction of tanks of various sizes by the East Bay Municipal Utility District, valuable experience was gained through difficulties, particularly with the earlier structures. Improvements were made until there has been developed a technic of design and construction that yields uniformly satisfactory results, with economy of cost. Still further reduction of cost will no doubt be accomplished with improvements in materials, particularly in the strength and machining qualities of steel.

An example of the possibilities in the steel bands is the use of wire-wound construction by the Preload Co. Drawing of the steel greatly increases its strength, so that a commercial grade steel wire of 0.14-in. diameter has an elastic limit of 185,000 psi. When wound on the tank at a prestress of 150,000 psi., the builders claim a reduction of 75 per cent in the quantity of steel required, as compared with the construction using a similar steel in large rods.

Following is a description of the structural details utilized by the East Bay Municipal Utility District in its latest prestressed tanks and reservoirs.

The foundation ring is poured entirely separately from the floor slab in order to afford the highly desirable

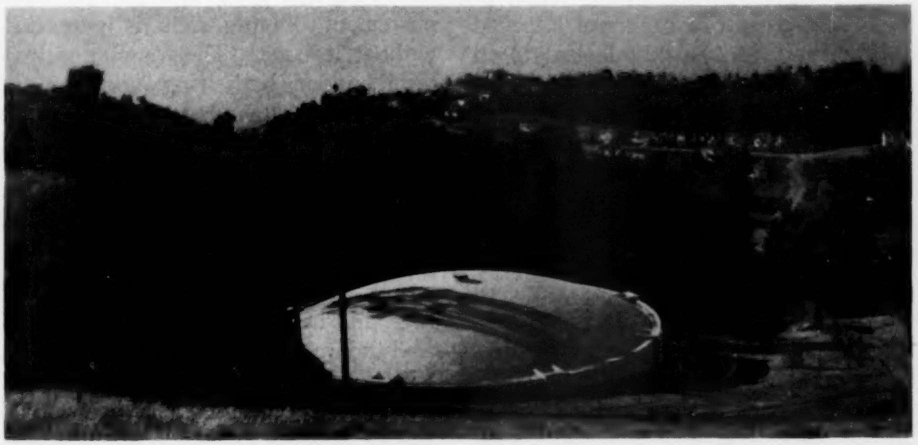

FIG. 2. Montclair Reservoir—1.5 mil.gal.

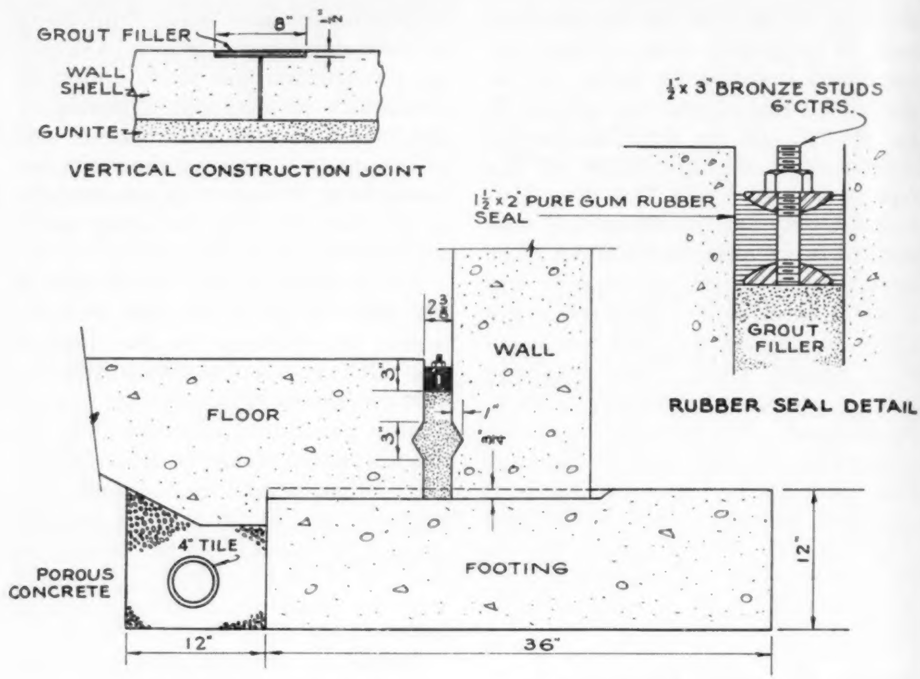

FIG. 3. Sections Showing Details of Joints

freedom to the latter of expanding and contracting without cracking. The method of doing this is shown in Fig. 3. Although the floor is not attached to the ring, it is firmly locked to it, and only minor relative vertical motion is permitted. In early structures, the space between wall and floor slab was filled with a mixture of sand, cement and iron dust. Oxidation of the iron tends to cause swelling and sealing of the joint. However, the wall movement due to changing pressures continually breaks this seal and slight leakage usually results. All later tanks have only the lower part of the joint filled in this manner, the true seal being in the form of a $1\frac{1}{2} \times 2$-in. pure gum rubber strip compressed between galvanized steel half-ovals through which $\frac{5}{8}$-in. bolts are placed at 6-in. intervals, as shown in Fig. 3. In this way, the movement of the walls is permitted without leakage. The foundation material under both ring and slab is sprayed with emulsified asphalt before the concrete is poured, to prevent absorption of moisture from the mix. The ring is reinforced by four $\frac{5}{8}$-in. round circumferential bars, tied by $\frac{5}{8}$-in. round radial bars, 12 in. center to center. No joints are provided in the ring, and hence radial cracks will form at random. The surface is finished with a steel trowel to produce a low degree of friction under the wall area. Radial grooves as shown are provided to produce tangential shear resistance

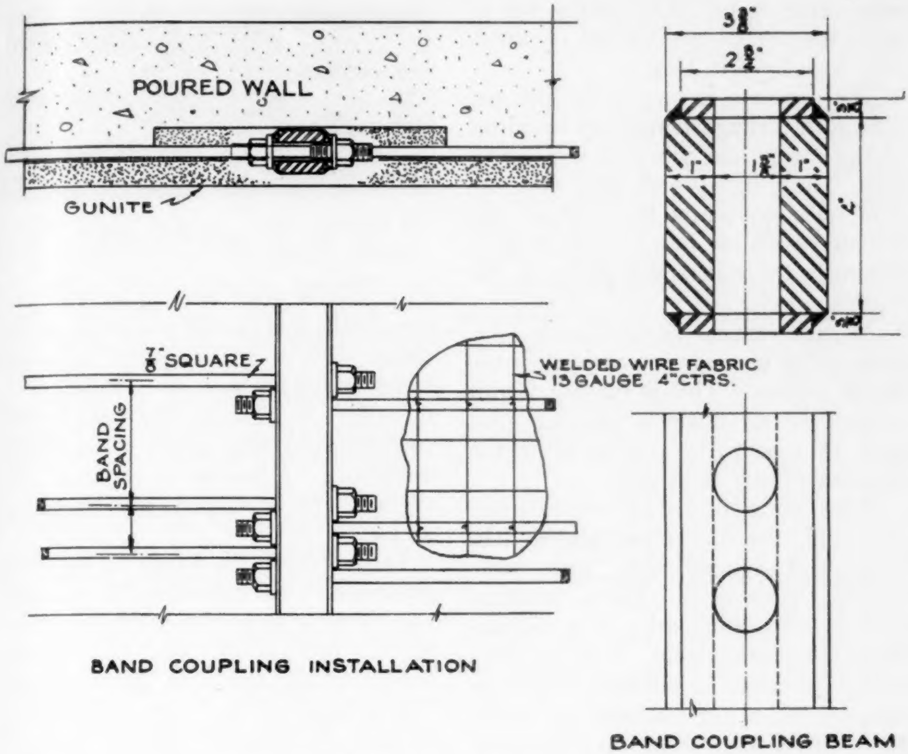

FIG. 4. Details of Tank Bands

and annular grooves are utilized to avoid relative vertical movement between wall and floor slab.

The floor and walls are of concrete containing six sacks of cement per cubic yard, producing a 28-day strength of about 3,500 psi. Great care is taken in placing and vibrating the mix, so that the maximum density is produced. Interior joints in the floor are $1\frac{1}{4} \times 1\frac{1}{2}$ in., as shown in Fig. 3, spaced at about 40-ft. intervals. Just prior to filling the reservoir, the joints are filled with a latex and oil compound consisting of 19 parts by volume latex, 66 parts oil, 6 parts Portland cement and 5 parts sulfur, mixed hot. For good bond of the material, care is taken to have the joint strictly clean and dry before pouring. The floor slopes slightly toward the drains and the surface is troweled to a smooth finish. All lower outlets are made through the bottom slab and not through the wall.

The side walls are poured continuously from bottom to top, and in lengths of 30 to 40 ft. Light reinforcing is provided, consisting of $\frac{3}{8}$-in. round bars spaced 12 in. center to center vertically and $\frac{1}{2}$-in. round bars spaced 18 in. center to center horizontally. Steps of 2 in. are made on the inside surface to increase the thickness as required, the minimum thick-

ness being 6 in. The forms are of ⅜-in. waterproof resin-glued plywood, 4 ft. wide by 8 ft. long.

The concrete is poured in lifts not over 8 ft. through temporary openings in the forms and vibrated with great care. Any honeycomb that still occurs must be repaired thoroughly. Alternate panels are first poured so as to minimize the contraction space at the vertical joints.

At each vertical joint a recess ½ in. deep and 8 in. wide is provided in the inside surface. This is plastered with a thick mortar made of one part iron dust to two parts cement after the bands are fully tightened.

When the walls are not less than ten days old, the bands are placed. In early tanks round rods with turnbuckles were used. Many practical and expensive difficulties were encountered with this system. The bars had to be assembled in advance in strings long enough to reach around the structure, carried by men into position, and held there until tightened enough to support the band by friction. In our largest reservoir, this would have involved over 500 ft. of bars, and a large crew of men to carry them, this group being idle a large part of the time. Also, the rods had a tendency to roll while the turnbuckles were being tightened, which made necessary other men with Stillson wrenches to hold them.

A decided improvement in technic has been developed by the district to prevent this waste of manpower. Vertical steel beams built up from plates, as shown in Fig. 4, are now being utilized. Holes for the bars are provided at the exact spacing required, and three men can place and tighten all of the bars, with efficient use of their time. It is found that square bars are better than round ones, since

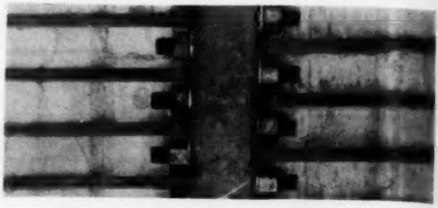

FIG. 5. Band Assembly

they provide good bearing on the concrete walls and do not roll when tightening. The torque required on a nut being less than that on a turnbuckle, the effort in bringing the bars to the presently-used high stress is materially decreased. A washer is used and the threads are lubricated with a heavy grease.

In tightening the bands to the final prestress, it is necessary to go over them at least three times, since increasing the pull on one band will slacken somewhat the stress on its neighbors. The amount of final torque is limited by use of a special wrench designed for this purpose, which shears a sixpenny copper nail when the force exerted on the wrench is the maximum required.

During the tightening process, at least one man hammers vigorously on the bar along its full length to keep it moving, and to force it into intimate contact with the concrete wall. If this work is not thoroughly done, the friction against the concrete will prevent a uniform stress. Extensometer tests have proven that a practically uniform stress results if proper technic is followed (Fig. 5).

The allowable tension in the steel will depend upon the quality of the metal used. Ordinary carbon steel, such as is used for structural purposes, has an elastic limit of about 30,000 psi., and should not be stressed higher

than 20,000 psi. Economy dictates that an alloy steel of much higher strength be used, however, the only limit being its workability in upsetting and threading. In all recent tanks a manganese steel containing about 0.85 per cent of the alloy and 0.40 per cent carbon has been used. This results in an elastic limit of approximately 65,000 psi. and ultimate tensile strength of about 100,000 psi. This steel is stressed to 40,000 psi., including about 5,000 psi. allowance for possible swelling due to saturation. The concrete, although having a test compressive strength of at least 3,500 psi., is stressed to only 500 psi. This precaution appears to be in order, particularly in large diameter tanks, in view of the thinness of section and the possibility of buckling of the walls.

As the bands are tightened, wire ties are placed under them, and these are used to attach a 4 × 4-in. × 13-gage welded wire mesh over the entire area to act as reinforcement for the 2-in. gunite coating applied over the surface. In tanks whose depth is such as to require two layers of steel bands, the first layer is stressed sufficiently above normal so that with the addition of a second layer over the gunite coating, the stress will be reduced to that assumed in the design. This is discussed later herein.

Scaffolding is built both inside and out, with operating platforms at 8-ft. intervals. Form ties are the standard rod-and-cone type, the holes being firmly calked with cement after the forms are removed. All exposed concrete surfaces are cured with Hunt Process after pouring.

Roof Structure

In tanks having a domed roof, extra bands are provided around the top. In a 93-ft. diameter tank the dome is a spherical segment of 97-ft. 9-in. radius, and rises 10 ft. $\frac{7}{8}$ in. above the side walls. The thickness is 3 in., and six bands are required to support it. The

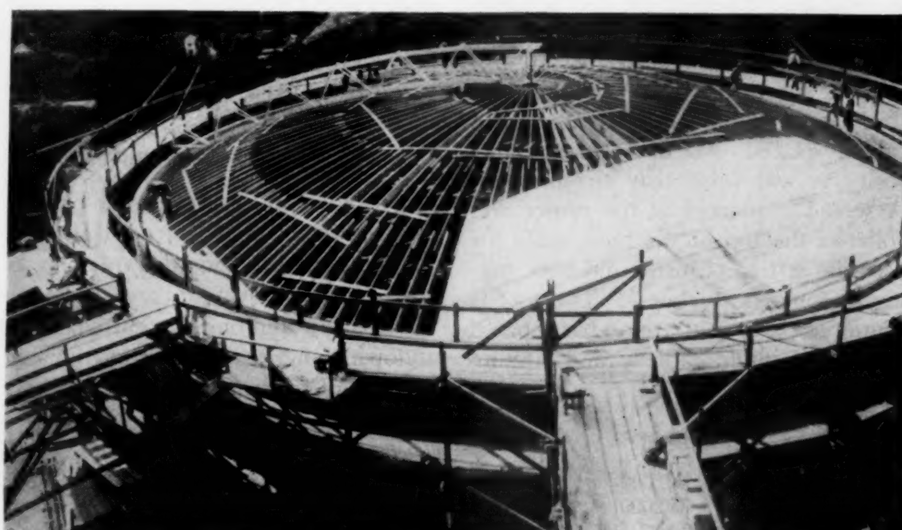

Fig. 6. Roof Framing, Burdeck Reservoir—1.5 mil.gal.

FIG. 7. Crockett Reservoir—1 mil.gal.

FIG. 9. Carisbrook Reservoir—3.5 mil.gal.

FIG. 8. Joaquin Miller Reservoir—3 mil.gal.

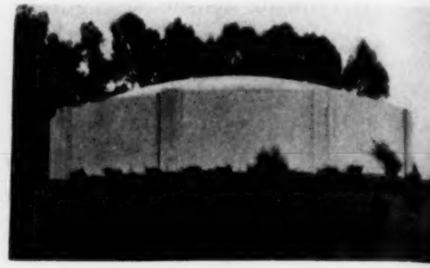

FIG. 10. Berkeley View Reservoir—1 mil.gal.

top bands are not fully tightened until the dome has cured for at least ten days. Tightening at this time raises the dome slightly from the forms, and greatly facilitates their removal.

The forms for the dome are of 1 × 6-in. boards, supported on radial joists whose upper surfaces were cut to the proper curvature. The boards are applied as shown in Fig. 6, and are relatively easy to lay as compared with radially-placed boards over parallel joists as was previously the practice. A screed is pivoted at the center and rolls on the top of the tank walls for accurate setting of forms and later gaging of concrete thickness. The roof is reinforced with $\frac{3}{8}$-in. round bars spaced 12 in. maximum radially and circumferentially.

Tanks of more than 93 ft. in diameter, built by the district, have flat slab roofs designed in the standard manner. Esthetic considerations rather than construction difficulties have dictated the limitation of domed roofs to such sizes (Fig. 7, 8, 9 and 10).

A generous screened ventilator is mounted in the center of the roof, and an access manhole is placed at the edge.

Costs of Prestressed Tanks

All tanks and reservoirs of the prestressed type were constructed between 1934 and 1942. Some were built by the district's own forces, some by WPA labor and one by contract. The following figures are from the cost records of twelve structures.

No. of Structures	*Capacity gal.*	*Average Cost per mil. gal.*	*Remarks*
2	200,000	$43,049	Gunite construction, dome roof
1	750,000	35,610	Dome roof
5	1,000,000 to 1,500,000	30,336	Dome roof
3	3,000,000	22,956	Flat slab roof
1	3,500,000	26,622	Flat slab roof, heavy excavation

The costs of those built by WPA labor were modified to represent as nearly as possible the figures that would have resulted if the work had been contracted. All figures are for the complete structures, including excavation, backfill, fencing, overhead, etc.

Basic Principles of Design

The principles involved in the design of these tanks are very simple and the construction is such that the theoretical stresses are very close to the actual. When the tank is empty, the concrete wall must support all of the tension of the bands without exceeding the design limit, generally taken as 500 psi. When the tank is full, the concrete wall has its minimum stress, preferably slightly above zero, and the steel bands receive their maximum tension.

FIG. 11. Section of Horizontal Ring— 1 ft. high

Figure 11 shows the cross-section of a horizontal ring 1 ft. high imagined to be cut from the walls of a concrete tank. The area of cross-section of one side of the ring is denoted as A_c. The ring is encircled by steel bands, whose total area is A_s. The tension in the bands is adjustable by means of threaded nuts or turnbuckles, and they are now placed under an initial unit stress denoted as f_{si} so that the stress in the bands per foot of height will be $A_s f_{si}$. This will also create an initial stress in the concrete ring and, if f_{ci} be taken to represent this initial stress, the total stress in the concrete ring will be $A_c f_{ci}$. For equilibrium,

$$A_c f_{ci} + A_s f_{si} = 0, \qquad (1)$$

and hence

$$A_c f_{ci} = - A_s f_{si}$$

or

$$f_{ci} = - \frac{A_s}{A_c} f_{si} = - p f_{si} \qquad (2)$$

where p is the ratio of steel area to concrete area.

Now assume that the tank is filled with liquid whose weight per cubic foot is w. If the depth of the ring under consideration is d feet below the liquid surface, a uniform pressure of wd will be exerted against each square foot of its inside surface. The radius of this surface being r, the stress in each wall will be wdr (Fig. 12).

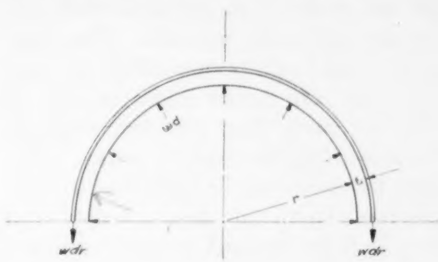

FIG. 12. Half Plan of Horizontal Ring— 1 ft. high

Due to the liquid pressure alone (and not considering the initial stresses previously introduced), the stresses in the steel bands (f_s) and in the concrete ring (f_c) would be in proportion to their moduli of elasticity, that is, in the ratio of $E_s \div E_c$ which is generally represented by the symbol n. Thus the composite area of concrete and steel may be represented as an equivalent all-concrete area equal to $(A_c + nA_s)$ and the new concrete stress due to the liquid pressure will be

$$\frac{wdr}{(A_c + nA_s)} = \frac{wdr}{A_c(1 + np)} \qquad (3)$$

Correspondingly, the stress in the steel will be

$$nf_c = \frac{nwdr}{(A_c + nA_s)} = \frac{nwdr}{A_c(1 + np)} \quad (4)$$

The combined stress in the concrete from the initial stress and the liquid pressure will be

$$f_c = -pf_{si} + \frac{wdr}{A_c(1 + np)} \quad (5)$$

and in the steel bands,

$$f_s = +f_{si} + \frac{nwdr}{A_c(1 + np)} \quad (6)$$

By use of these equations, the relation of areas between the steel bands and the concrete may be determined for any position in the tank wall and for any allowable stresses. The concrete should not be permitted to have less than zero stress when the tank is full, nor more than the maximum allowable when the tank is empty. The steel bands should be tightened to such prestress when the tank is empty that they will be stressed to the maximum allowable when the tank is full.

The maximum stress in the concrete with the tank empty will be, from Equation (2), $f_{ci} = -pf_{si}$.

A factor that has been neglected in the above discussion is the expansion of the concrete walls due to water soaking that occurs later. A reasonable assumption of the change in the coefficient of expansion will be about 0.0002 with a high degree of saturation. It is found that this creates an additional stress in the steel of about 5,000 psi. Under the assumptions used in the design, this stress should be allowed for in the initial stressing of the bars if the vessel will normally stand full.

The usual limit placed on the concrete stress is about 500 psi. and it is recommended that this be adhered to, particularly in large tanks. For small tanks the designer may consider raising f_c to as high as 650 psi. or more. The expansion due to water soaking is usually found to increase the concrete stress by about 100 psi.

Concrete of the high quality used for the walls will have a modulus of elasticity E_c of from 2,500,000 to 3,500,000. E_s for all grades of steel will be close to 30,000,000. Thus n, which equals $E_s \div E_c$ may range from 8.6 to 12. An average value of 10 is commonly used.

The problem, then, is to vary the thickness of concrete from top to bottom of the tank and the spacing of the bars so that the allowable stress limits are obtained, both for the concrete and for the steel. The minimum thickness of wall at the top is generally taken as 6 in. A thinner wall would be difficult to construct with adequate density because of the space required for reinforcing steel and the operation of the vibrator. In addition, the roof dome or slab must have proper support, which would not be provided by a thinner wall. The minimum spacing of the steel bands is taken to be 18 in. Theoretically the wall thickness would taper uniformly from top to bottom, but this would involve practical difficulties in form construction and hence the thickness is increased by steps of 2 in., these steps being on the inside surface only, in order that the bars that make up the bands will be of uniform length.

There is an obvious advantage in accomplishing the banding in the lower areas of the tank with a single layer of steel bands. Regardless of the

method of applying the bands, however, it is difficult to place them closer than about 4 in. apart due to the space taken by turnbuckles or wrench. If this is insufficient, then a second layer of steel will be necessary over a part of the wall height. The second layer is installed by prestressing the first layer to a higher degree than normal, covering it with gunite, applying the second layer of bands and tightening them to normal stress. The amount of prestress in the first layer is determined by noting that the change in stress in the composite section due to the tightening of the outside bands will be equal to $A'_s f_{si} \div A_c + nA_s$, and the change in the inside steel stress will hence be $nA'_s f_{si} \div A_c + nA_s$ in which A'_s represents the area of the outside layer of the steel. In view of the prior shrinkage of the gunite coating, its area is not included in determining the prestress of the outside layer of steel. The original tightening of the inside layer should be sufficiently above normal to cause it to return to normal when the outside layer is fully tightened.

Canada's Ground Water Resources From a Geological Aspect

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Presented on Apr. 19, 1944, at the Canadian Section Meeting, Niagara Falls, Can.

THE ground water resources of a country are dependent on many factors that interact in an extremely complex manner. Topography, temperature, precipitation, evaporation, surface runoff, absorption by vegetation, character of the soil and the nature and structure of the bedrock play important roles in determining the amount and composition of the underground water supplies. In a country as large as Canada, embracing an area of approximately 3,700,000 sq.mi., spread over 40 deg. of latitude and 85 deg. of longitude, with a relief extending from sea level to a maximum elevation on Mount Logan of 19,850 ft., and with an average annual precipitation ranging from less than 10 in. to over 160 in., a great diversity in the ground water conditions is to be expected (see Fig. 1).

Canada, moreover, possesses other distinctive features pertaining to the nature and distribution of its bedrock and its unconsolidated deposits, as well as to the distribution of its comparatively small population concentrated in relatively small areas, and these must be kept constantly in mind in any consideration of its ground water resources.

Physical Geography

Canada lies in the temperate and arctic zones extending from the 43rd parallel northward to the polar regions with normal mean temperatures ranging in some of the northern areas from 60° above zero to 30° below zero. In the sub-arctic regions are extensive areas of tundra, and in the polar regions vast areas of perpetual snow and ice. It probably possesses more bodies of fresh water than all the other countries of the world combined. Most of these water bodies are concentrated in that part lying along and north of the chain of lakes and rivers formed by the St. Lawrence and Ottawa rivers, the Great Lakes and Lake of the Woods, Lakes Winnipeg, Athabaska, Great Slave and Great Bear. The bedrock surface of 1,800,000 sq.mi. of this area consists largely of dense crystalline igneous rocks which are so compact and impervious that they permit little water to enter them, and yield little in return, most of their weathered upper parts having been completely removed by glaciation. The population within this vast area is meager and confined largely to mining settlements, lumber camps and trading posts. With such abundant surface water supplies available, the problem of ground water resources over this immense region is mainly one of academic interest.

In the relatively cold and moist mountainous region of western Canada, where the population is mainly confined to mining and lumber camps and

to settlements on the transcontinental railways that follow the three main transverse valleys, ample supplies of water are generally obtainable from mountain streams and springs. Here the investigations of ground water supply have been largely confined to those pertaining to the thermal springs at Banff, Jasper and Harrison Springs in the several national parks, and in the so-called "tropical valley" of the Liard River of northern British Columbia.

There are, however, many areas such as in Welland, Haldimand, Brant, Elgin and Essex counties of southwestern Ontario, in the Interior Plains region, and along that part of the Alaska highway lying between Dawson Creek and Fort Nelson in British Columbia, where the locating of satisfactory water supplies is a matter of real concern. In the Western Plains numerous examples can be cited of farms that were purchased, held for years, and finally abandoned due to failure to obtain adequate supplies of water. In other parts of this region satisfactory supplies of water were at first obtainable from wells, but as the population of the district increased, the available supplies have become inadequate, and dependence must be placed on retaining rainfall in dugouts, on bringing in the water from distant sources by irrigation ditches or pipes, or on exploring by wells and boreholes for deeper underground water supplies. The Winnipeg water supply, at first derived from artesian wells, is now piped from Shoal Lake 98 mi. distant, but ground water supplies are being used in air-conditioning installations.

Large areas in western Canada are awaiting settlement, but in some of

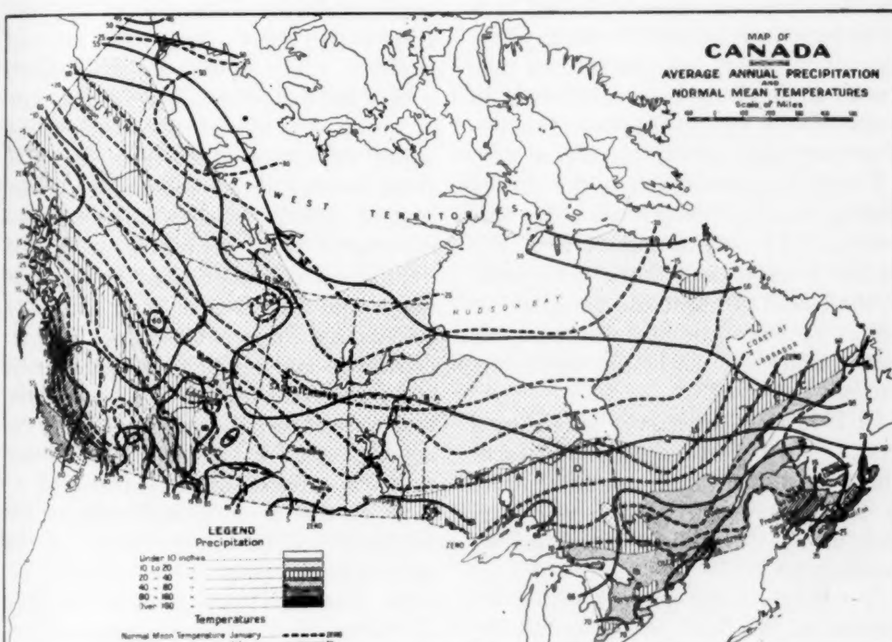

FIGURE 1

them, the probability of obtaining adequate ground water supplies at shallow depths appears to be very slight. In such areas a thorough investigation of the ground water supply or the possibilities of irrigating the areas is of prime importance, and the land should be withheld from settlement until the evidence of satisfactory supplies is obtained. In some areas the desired information can only be secured by test drilling.

Ground Water Investigations by the Geological Survey of Canada

Although the investigation of the ground water resources of a country is universally regarded as a function of its geological survey, until recent years comparatively little work of this nature has been undertaken by the Geological Survey of Canada. As a result, most of the information pertaining to ground water has been collected as a secondary consideration during the course of other field work. A few special studies have been carried out in areas within which adequate supplies of ground water were urgently needed.

The first report issued by the survey dealing entirely with ground water was one by F. D. Adams and O. E. Leroy on the artesian and other deep wells on the Island of Montreal, published in 1901. A more comprehensive report on the subject by C. L. Cumming was published in 1915.

In 1915 also, the survey published a report on the discovery of the artesian water supply of southeastern Alberta by D. B. Dowling. This report was brought up to date and amplified by Dowling in 1922.

A report on the ground water resources of Regina, Sask., by H. E. Simpson was published in 1929. This was followed in 1930 by a report on the ground water resources of Moose Jaw, Sask., by W. A. Johnston and R. T. D. Wickenden. In 1931 and 1932 D. C. Maddox reported on certain artesian areas in southern Saskatchewan and in 1934 W. A. Johnston reported on the surface deposits and ground water supply of the Winnipeg map area in Manitoba.

In 1933 and 1934 a detailed survey on the ground water conditions in Ottawa and vicinity was made by D. C. Maddox and M. Mahoney and a report was compiled.

In 1935 a very detailed ground water survey was made, under the supervision of the author, of southern Saskatchewan, extending from the international boundary to the northern boundary of Township 32. An area of 80,000 sq.mi., embracing 2,500 townships and 225 rural municipalities, was covered, records of 60,000 water wells were obtained and samples of 720 representative wells were collected and analyzed. The results of this investigation were made available to the public in the form of reports on the ground water resources of each of the 225 rural municipalities covered. As the cost of printing such a large number of reports was prohibitive, a limited number of mimeographed copies was made and distributed to a carefully selected list comprising various federal, provincial and municipal departments, and those companies and organizations that were especially concerned with the development of underground water supplies. Three copies were sent to each of the municipality's offices for reference use by the residents of the municipality, who were notified by press that the reports were available and where they might be consulted.

During 1935 well data were also collected over an area of approximately

20,000 sq.mi. in east-central Alberta, and approximately 15,000 sq.mi. in west-central Saskatechewan by parties under the direction of G. S. Hume and C. O. Hage. These records and three reports in manuscript are on file in the Borings Section where they may be consulted if desired.

In 1936 approximately 2,500 well records were obtained by R. T. D. Wickenden over an area of approximately 7,500 sq.mi. in southeastern Alberta.

In 1936 and 1937 a detailed ground water survey was carried out by J. F. Caley and H. N. Hainstock, covering approximately 800 sq.mi. in southern Ontario, embracing the following eight townships: Markham, Pickering, Scarborough, Whitchurch, Vaughan, King, Toronto Gore and Albion. Records were obtained of approximately 8,700 wells, and water samples from 280 representative wells were collected and analyzed. A report on each of these townships was prepared and is available for reference and for answering inquiries received.

Special investigations have also been made upon request by officers of the Geological Survey on ground water conditions of a number of localities including Winnipeg, Richmond Hill and Essex.

Water well records have also been received from various provincial departments, the University of Saskatchewan, drilling contractors and individual drillers. The Geological Survey has also secured from the Dominion Department of Transport the records of the large number of water wells that have been drilled within the last four years in an effort to secure adequate water supplies for the numerous airports established across Canada. The Geological Survey appreciates the co-operation extended by these organizations and would welcome all information on ground water conditions which could be supplied by engineering firms or individual engineers.

From its inauguration in 1908, the Borings Section of the Geological Survey has been engaged in collecting, assembling and interpreting water data from all available sources, and the files contain records in excess of a hundred thousand water wells.

In addition to the water well data, there are also on file in the Borings Section records and rock samples of many thousands of wells drilled for oil or gas, or coal or test holes to determine the bedrock structure. These records and the 790,000 rock samples on file are of inestimable value in helping to solve the many stratigraphical and structural problems that arise. As an aquifer or water-bearing horizon acts in much the same manner, with respect to areal extent, thickness and subsurface structure as does a seam of coal or a stratum in which oil and gas occur, the same principles are applicable to all. Among the problems that arise for solution are such as (1) the possibility of encountering artesian water flows in an area, (2) the probable limits of such an area of artesian flow, (3) the permanency of known water supplies, (4) the probable height to which the artesian water will rise, (5) the estimated depth at which the top of the aquifer will be encountered, (6) the mode of occurrence of the water, and (7) the quality and temperature of the water that will be obtained.

The data on file in the Borings Section, comprising geological maps, reports, memoranda, structure sections, topographical maps, well and borings records and drill cuttings, are all made

use of in arriving at a conclusion as to the probability of obtaining water supplies in untested territory. In this, even negative information is of value as it often saves the expenditure of funds that would be spent in drilling dry holes. It is such data that form the basis for the answering of many hundreds of inquiries received each year from land owners throughout Canada as to the probability of finding water on their properties and the depth to which it is necessary to drill. Owing to the importance which air-conditioning by the use of ground water has attained, data on ground water conditions in cities are often of value even when the main supply is obtained from other sources.

Ground Water Conditions in Unconsolidated Deposits

The most important source of ground water supplies in Canada is the unconsolidated deposits, consisting of glacial deposits, post-glacial lacustrine deposits, marine clay deposits and recent alluvial deposits. The most important of these are the glacial deposits, which are to be found widely distributed through Canada. In fact, the glacial drift is a greater source of water supply in Canada than all the bedrock formations combined. In many places, however, the glacial drift does not contain adequate supplies of water, and it is necessary to drill through it into the underlying bedrock formations.

In some areas, the glacial drift is overlain by clays and silts that were deposited in extensive post-glacial lakes formed on the retreat of the ice front. In other areas along the low coastal plains, the glacial drift may be covered by a stratum of clay deposited when these areas were submerged beneath the sea. In still other areas the drift cover consists largely of recent alluvium that has been deposited by streams or lake deposits, or other pre-existing unconsolidated deposits that have been reworked by wind action.

Glacial Deposits

During the glacial period practically all of Canada, except the highest parts of the Rocky Mountains, the northern part of the Yukon, and some high lands in Gaspe, Que., and in Labrador, was buried beneath extensive ice sheets inferred to be several miles in thickness at their centers (Fig. 2). These ice sheets, designated the Cordilleran, the Keewatin, the Patrician and the Labradorean, due to the superincumbent weight of the ice, moved outward from their centers located in the Rocky Mountains, in Keewatin District west of Hudson Bay, in Patricia District south of Hudson Bay and in Labrador east of Hudson Bay. A fifth center of glaciation was in Greenland, and the existing Greenland ice cap is but a descendant of the more extensive ice sheet which extended westward and covered Ellesmere and the adjacent Arctic islands. It is possible that still another ice cap existed in the western Arctic islands.

From most of these central areas the soil and weathered bedrock have been removed by ice erosion and have been distributed as glacial drift of various types over areas farther out. The great mass of this glacial drift, representing several drift sheets, is in the form of "ground moraine," a layer of very uneven thickness of "boulder clay" or "till" that was deposited directly by the moving ice. In some areas the ground moraine has been molded by the overriding ice into a series of elongated

hills termed "drumlins" or "drumlinoids," the longer axes of which parallel the direction of ice movement.

In some regions the glacial drift is a mixture of boulder clay and stratified sands and gravels in variable proportions, deposited in the form of belts, designated as "terminal moraine" or "recessional moraine." This type of topography is generally characterized by hillocks and undrained depressions. Such deposits are, in places, several hundred feet in thickness, a mile or more in width and many miles in length. They lie transverse to the direction of the ice movement and are believed to have been formed at the front of the ice sheet and to mark stationary periods at its maximum advance or during its recession.

In some places there are ridges of stratified sand and gravel, termed "eskers," that run in sinuous courses roughly parallel to direction of glaciation and often are traceable for many miles. They are believed to have been deposited by streams that ran beneath the ice sheet. In some areas the drift consists largely of stratified sands and gravels in the form of alluvial fans, aprons, deltas, valley trains and outwash plains that were deposited by waters issuing from the ice front.

As the ground moraine consists largely of an unassorted mixture of boulders and finely ground-up rock and clay, it is very impermeable and consequently of itself yields very meager water supplies. It generally includes, however, isolated irregular-shaped bod-

FIGURE 2

ies of sand and gravel that yield small supplies of good water.

In the terminal moraine, a large proportion of the deposit consists of sand and gravel and here the ground water supplies are more abundant. Eskers, alluvial fans, deltas and outwash plains consist largely of beds of well-stratified sands and gravels, which yield generally abundant supplies of good water.

Post-glacial Lacustrine Deposits

Most of the drainage in Canada is northward and as the Keewatin, Patrician and Labrador ice sheets advanced and receded (several such advances and recessions are known to have occurred), there was impounded along the fronts of the various ice lobes that extended up the major drainage courses, the water derived from the inflowing streams and from the melting of the ice. The levels of the lakes thus formed rose in elevation until the lowest outlets were reached, whereupon the waters escaped through these outlets and established new drainage courses often at variance to the pre-existing drainage.

From the occurrence of beaches, cutbanks, deposits of stratified silts and clays, reworked glacial drift and interglacial deposits, it has been possible to delineate the various areas covered by these glacial and post-glacial lakes. Among the larger are the following: Lakes Duluth, Chicago, Maumee, Saginaw, Whittlesey, Warren, Algonquin and Nipissing, that record various stages in the lakes formed by the ice sheets in the Great Lakes basin; Lake Ojibwa-Barlow that was formed on the north slope of the St. Lawrence-Hudson Bay Divide in Ontario and Quebec; Lake Souris, Lake Agassiz and Lake Churchill in Manitoba; Lakes Regina, Saskatoon, Saskatchewan, Gravelbourg, Johnston and Great Sands Hills in Saskatchewan; a series of lakes formed along the valleys of the Oldman, Bow, Saskatchewan, Peace and Athabaska Rivers in Alberta; and the ancestral Great Slave Lake and possibly Great Bear Lake in the Mackenzie River drainage basin of the Northwest Territories.

In these lakes, thick deposits of silt and clay were laid down, together with occasional layers of sand which were deposited under near-shore conditions. The clays and silts are comparatively impermeable, and, where thick, prevent the water from entering the underlying drift which consequently yields only very meager supplies of water. Water is occasionally found, however, in the thin beds or lenses of alluvial sand within or below the clays, or in the glacial drift below them, that have their intake areas on the higher slopes, and it is often found under conditions favorable to the occurrence of artesian wells.

Post-glacial Marine Deposits

In late glacial and post-glacial time much of the low coastal plains of eastern and northern Canada, including the St. Lawrence Valley, Champlain Lake and the lowlands west to Lake Ontario and beyond Ottawa, were submerged by a transgressing sea. Streams entering these embayments deposited their sands as interleaved lenticular deposits between the less permeable beds of silt and clay that were being deposited by the quiet marine waters. These deposits generally dip away from the uplands. Although seldom continuous over wide areas, the porous nature of these beds and their position between beds of impervious clay make them generally a source of artesian water supplies. The water en-

ters these porous beds on the marginal uplands and the "flowing wells" are confined usually to the lower areas where the clay has been penetrated and the aquifer tapped. In the low-lying areas the water in the sediments beneath the marine clay is usually too salty to be usable.

The upper limit of these marine deposits is indicated by highest marine shorelines as evidenced by beaches, boulder ridges and associated areas in which the glacial drift has been completely removed from the bedrock by wave action. Elevation determinations on this ancient shoreline reveal that it has been differentially uplifted. The shoreline ranges in elevation from 400 ft. at the south end of Lake Champlain to 500 ft. at the north end of the lake, about 600 ft. at Montreal and 690 ft. at Ottawa. It continues the northward rise to the south end of James Bay where it attains the maximum elevation of about 900 ft. Beyond this the marine shoreline decreases in elevation, becoming less than 300 ft. above sea level along the north coast of Labrador. In the Arctic islands the beaches lie generally less than 500 ft. above sea level.

Ground Water Conditions in Bedrock Formations

As the ground water conditions in bedrock formations are largely controlled by the nature of the individual rocks and the substructure of the strata over large areas, the ground water supplies of Canada could be most adequately described by a detailed discussion of the water possibilities of the individual rock formations as they occur in different parts of Canada. The vast extent of territory, the variety of conditions that prevail in the different areas and the limited space available, permit, however, only a very generalized summary of the ground water conditions throughout Canada.

In order to refresh the reader's memory with respect to the more elementary principles of geology and give a clearer understanding of the stratigraphical succession as depicted in the accompanying geological map and structure sections (Fig. 3), a few explanatory remarks are here given. From a study of the nature of the rocks as exposed in numerous natural sections and well borings, their fossil contents, the thicknesses of the strata, their geographical distribution and stratigraphical and structural relationships, geologists have been able to construct a geological column as here shown depicting the orderly succession of the strata, the development of life, and the major physical events that have taken place in the earth's history, such as vulcanism, mountain building, base-levelling, climatic changes and glaciation. On the bases of these changes it has been possible to group the individual beds into "members," "members" into "formations," "formations" into "series," "series" into "systems," and "systems" into major units termed "groups." A "group" is usually separated from the adjacent "group" by a major stratigraphical break or unconformity that indicates that the rocks of the earlier "group" had been folded, elevated and base-levelled before the deposition of the beds of the suceeding group.

Corresponding to the above major physical changes there were abrupt major changes in the development of life on the earth. On the basis of these major biological changes the geological column has been divided into five groups, the time equivalent of which is the era. These five eras are the

Archaean, Proterozoic, Palaeozoic, Mesozoic and Cenozoic.

Each of the above eras has been subdivided into periods such as the Cambrian, Ordovician and Silurian, the time interval required for the deposition of a system. The period is further subdivided into epochs, etc. The areal relationship that exists between rocks of these different groups is shown on the structural sections in Fig. 3.

Canada is usually divided into six physiographic provinces as shown in Fig. 4, i.e., (1) Appalachian Region, (2) St. Lawrence Region, (3) Canadian Shield, (4) Interior Plains, (5) Cordilleran Mountain System, and (6) Arctic Archipelago and Hudson Bay Lowland. In that rocks of several of the foregoing "groups" occur in the same physiographic provinces, and rocks of the same "group" occur in several of these physiographic provinces under similar stratigraphical and structural conditions, these six physiographic divisions are not well adapted to serve as the basis for classifying Canada's ground water resources. A much better basis for this classification is to divide Canada first into its three major structural or tectonic units which are separated from one another by natural structural boundaries, i.e., faults of large displacement, and which

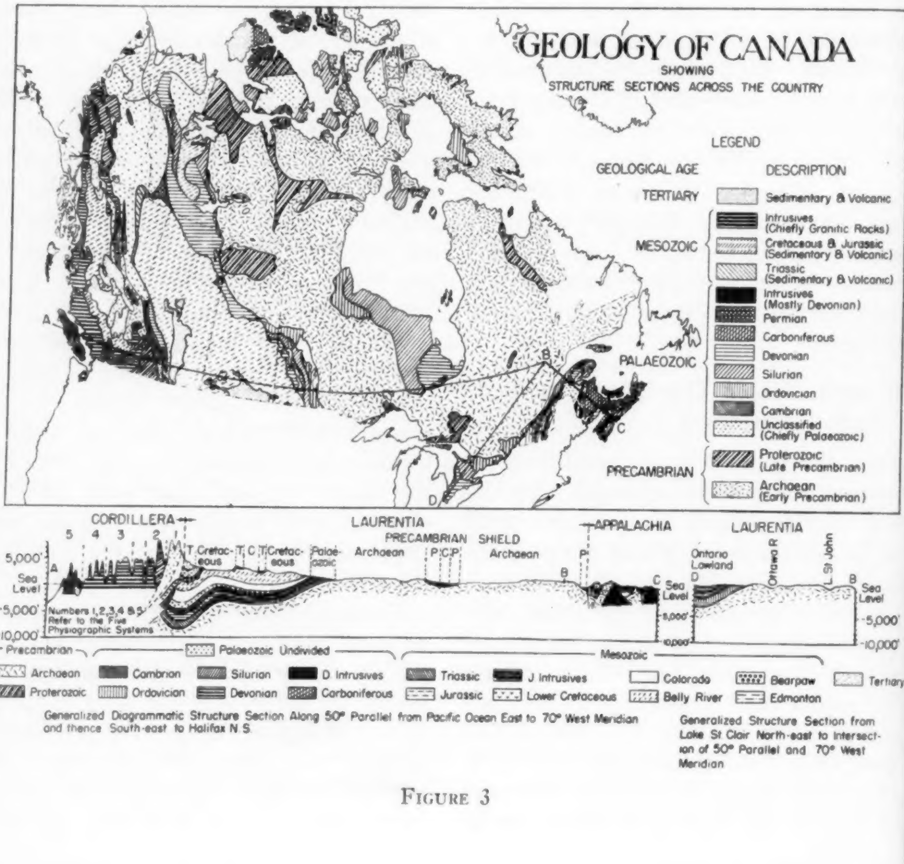

FIGURE 3

differ from one another greatly in their geological histories. Such a division has already been made.

The central or larger unit covers the vast region of Canada formed by ancient Precambrian crystalline rocks partly overlain by younger nearly flat-lying sedimentary formations which embrace rocks of the three succeeding eras: Palaeozoic, Mesozoic, and Tertiary. This structural unit, to which the name "Laurentia" has been given, embraces the Canadian Shield, the Interior Plains, the St. Lawrence Region, and the Arctic Archipelago and Hudson Bay Lowland physiographic provinces. It is separated on the southeast from the folded Appalachia structural unit by a major fault that extends from Lake Champlain northeasterly to Quebec City, and thence down the St. Lawrence River, passing presumably south of Anticosti Island and through the Strait of Belle Isle. It is separated on the west from the highly folded and faulted mountainous Cordillera structural unit by a zone of pronounced faulting that extends from the international boundary northward 900 mi. to beyond Liard River, and thence along the east base of the folded mountains north to the Arctic Coast.

The rocks of most of Laurentia have been only slightly deformed since the beginning of the Palaeozoic era, and the differences that exist in sediments of the different eras represented are largely those of the original deposition and later cementation. The rocks of the Precambrian age, including both Archaean and Proterozoic, are compact and impervious; those of the Palaeo-

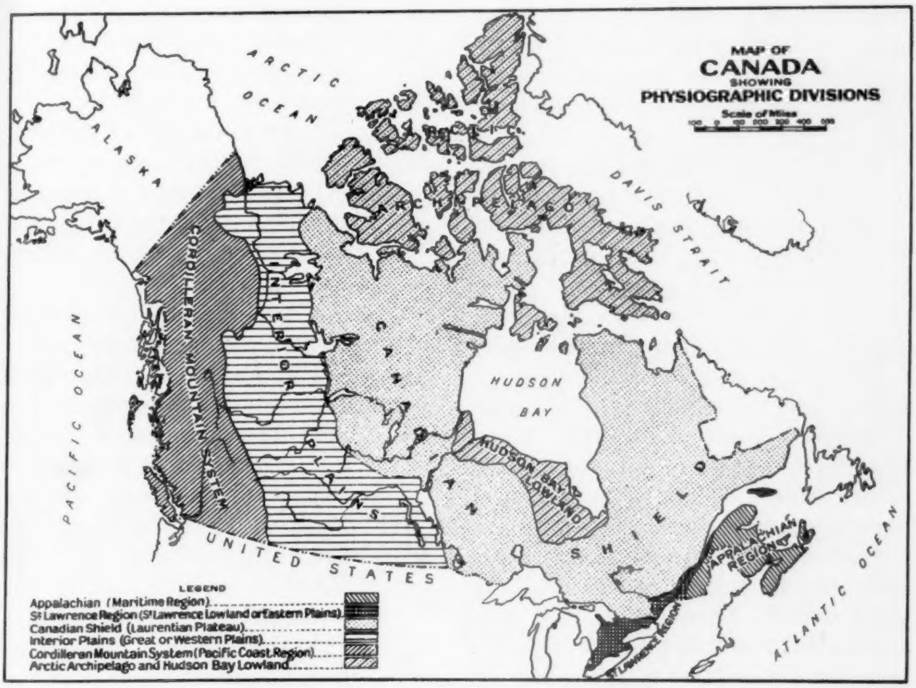

FIGURE 4

zoic age are more permeable; those of Mesozoic age are much more porous; and those of the Tertiary age are very loose and open in texture. Igneous rocks belonging to all four eras are compact and impermeable.

On the other hand, the rocks in the Appalachia and Cordillera structural units were subjected to intense mountain-building deformation, the former during the Palaeozoic, and the latter during Palaeozoic, Mesozoic and Tertiary eras, and the original differences that existed in the porosity of the sedimentary rocks of the different eras have been largely obliterated. Moreover, the rocks are so steeply inclined that the belts of the different groups are generally too narrow to be properly delineated on a map of small scale. The Cordillera and Appalachia structural units, therefore, do not lend themselves to a satisfactory subdivision into four stratigraphic units corresponding in age to the four eras as does the Laurentia region structural unit.

Because water wells drilled into bedrock seldom exceed a few hundred feet in depth, and usually do not penetrate below the erosional unconformity that generally marks the base of the group of rocks in which the wells have been started, each of the stratigraphic units is here restricted to those areas in which rocks of the same era outcrop or immediately underline the drift. These stratigraphic units in turn have been further subdivided on a geographical basis into ground water provinces.

Each of these ground water provinces can be further subdivided into sub-provinces according to the rock system that outcrops or immediately underlies the drift, or even into smaller areas or belts corresponding to the "series" or individual geological formations that may form the underlying bedrock.

This subdivision is as follows:

A—Laurentia Structural Unit.

- I—Canadian Shield — areas in which igneous or metamorphic Precambrian rocks outcrop or immediately underlie the drift.
  - (1) Archaean ground water provinces—areas in which rocks of Archaean age outcrop or underlie the drift.
  - (3) Proterozoic ground water provinces—areas in which Proterozoic rocks outcrop or immediately underlie the drift.
- II—Palaeozoic stratigraphic unit or Palaeozoic Lowlands—areas in which Palaeozoic rocks outcrop or immediately underlie the drift.
  - (1) Arctic Islands Palaeozoic ground water province.
  - (2) Hudson Bay Palaeozoic ground water province.
  - (3) Anticosti Palaeozoic ground water province.
  - (4) St. Lawrence Palaeozoic ground water province.
  - (5) Ontario Palaeozoic ground water province.
  - (6) Manitoba Palaeozoic ground water province.
  - (7) Athabaska Palaeozoic ground water province.
  - (8) Mackenzie Basin Palaeozoic ground water province.
  - (9) Small Palaeozoic outliers.
- III—Mesozoic stratigraphic unit or Great Plains—areas in which Mesozoic rocks outcrop or immediately underlie the drift.
  - (1) The Central Plains Cretaceous ground water province.
  - (2) Great Bear Lake Cretaceous ground water province.

(3) Good Hope Cretaceous ground water province.

(4) Mackenzie River Delta Mesozoic ground water province.

(5) Arctic Islands Mesozoic ground water province.

(6) Moose River Basin Cretaceous ground water province.

IV—Tertiary stratigraphic unit—areas in which strata of Tertiary age outcrop or immediately underlie the drift.

(1) Southern Saskatchewan Tertiary ground water province.

(2) Alberta Syncline Tertiary ground water province.

(3) Norman Tertiary ground water province.

(4) Arctic Islands Tertiary ground water province.

B—Appalachia Structural Unit.

(1) Precambrian and Igneous ground water province.

(2) Deformed Palaeozoic ground water province.

(3) Undeformed Palaeozoic ground water province.

C—Cordillera Structural Unit.

This structural unit corresponds to the Cordilleran Mountain System which consists of the following physical sub-provinces: (1) Rocky Mountain, (2) Cassiar-Omineca, (3) Interior Plateau, (4) Coast Range and (5) Insular Systems.

Ground Water Conditions in the Three Major Structural Units and Various Ground Water Provinces

Laurentia Structural Unit

I. Canadian Shield—This is a region of rugged topography with numerous lakes and rivers, and with a cover of glacial drift that overlies Precambrian crystalline rocks. The ground water supplies of this region are derived largely from sand beds that occur in the glacial drift or from fractures and joint planes in the bedrock. In the areas where the glacial drift is overlain by post-glacial lacustrine clays or marine clays, the water occurs under artesian conditions from aquifers that lie between the clay and the underlying bedrock.

(1) *Archaean Ground Water Provinces*—The Archaean rocks underlie the greater part of the Precambrian shield. Over most of the area they consist largely of highly deformed and metamorphosed lava flows (greenstones) and minor amounts of ancient rocks that represent sediments of the earth's crust. These rocks were invaded by extensive masses of granite which fused and similated most of its overlying cover. In the southeastern part of the shield in Ontario, Quebec and Labrador the earliest of these rocks are crystalline limestones and quartzites which are also invaded by granite. These limestone rocks are much more favorable for the transmission and storage of ground water in that they are intricately shattered and cut by numerous fissures and faults. Good supplies of water can generally be obtained from it within 100 ft. of the surface. The other rocks of the Archaean are impervious to water and the meager supplies obtained are from fissures or joint planes in the rock.

(2) *Proterozoic Ground Water Provinces*—The Proterozoic rocks comprise all the Precambrian rocks known or inferred to be younger than the Archaean. They are found covering large areas of the Canadian Shield, embracing the Arctic Islands, Copper-

mine River area, Great Bear Lake area, Lake Athabaska area, Nipigon-Copper Cliff-Cobalt areas of Ontario, Lake Mistassini and Swampy Bay River areas of Quebec, and Seal Lake area of Labrador. Within each of these areas the rocks embrace sediments and lavas, and at some places intrusive granitic rocks of considerable extent. Except in the vicinity of the intrusive bodies, the sediments are but slightly metamorphosed and in parts of the area they are nearly flat-lying with the physical character of rocks resembling that of the beds of the Palaeozoic, the next younger geological division. Even where the sediments are little deformed, however, they are very impervious due to deposition of silica or carbonates in the spaces between the grains of the rock. They consequently yield only meager supplies of water, except along the bedding planes of the lava flows, at unconformities, or in joints and fissures that cut the rocks to a depth of a few hundred feet.

II. Palaeozoic Lowlands—(1) *Arctic Islands Palaeozoic Ground Water Province*—These islands are largely uninhabited, and a consideration of the ground water conditions is therefore mainly of academic interest. Most of the drift is frozen and the water supplies used are derived largely from streams or from wells that are sunk beneath the frost zone into the underlying bedrock.

(2) *Hudson Bay Palaeozoic Ground Water Province*—Most of the ground water supplies required in this largely uninhabited area are derived from the glacial drift. Where the glacial drift is overlain by glacial lake clays or by marine clays, water under artesian conditions may be expected. Where the drift is thin or absent, variable supplies of water may be obtained from wells, sunk in the bedrock that consists largely of limestone with interbeds of shale and sandstone.

(3) *Anticosti Palaeozoic Ground Water Province*—Ample supplies of hard, but otherwise good water may be obtained from stratified beds of sand and gravel of glacial and post-glacial age. Where marine clay occurs water may be expected from aquifers that lie between it and the bedrock, generally under artesian conditions. Wells drilled into aquifers in the gently dipping Silurian and Ordovician limestones which underlie the unconsolidated deposits also yield good supplies of water of satisfactory quality.

(4) *St. Lawrence Palaeozoic Ground Water Province*—Good supplies of ground water are obtained from sandy aquifers that lie interbedded with or beneath the marine clays which occur widely distributed over this province. At and in the vicinity of Ottawa and Montreal, wells drilled into the Ordovician limestone and underlying Cambrian sandstones have generally yielded ample supplies of good water, but elsewhere in this province the deep Palaeozoic waters are generally highly mineralized. At Montreal numerous flowing wells have been obtained from aquifers and fractures in the Palaeozoic rocks.

(5) *Ontario Palaeozoic Ground Water Province*—Most of the ground water supplies in this province are derived from sand and gravel beds in the glacial drift that ranges in thickness from the thin veneer at the eastern and northern borders to over 100 ft. in southwestern Ontario. Where the drift is thin, water supplies are generally scarce and are derived from aquifers in the underlying bedrock formations. The waters from these

aquifers vary in quality with the type of bedrock, ranging from soft water of low mineralization to hard highly mineralized water, some of which is unfit for domestic use.

(6) *Manitoba Palaeozoic Ground Water Province*—The chief source of ground water in this province is from aquifers that occur in the glacial drift that underlies the clays of glacial Lake Agassiz, or from the upper part of the underlying bedrock. Flowing artesian wells from both these horizons occur in the Red River Valley area and these once formed the main supply for the city of Winnipeg. Good supplies are still obtainable from the upper part of the Stony Mountain limestone formation which extends in a northerly direction from Winnipeg, and which has a gentle westerly dip from its outcrop that lies to the east of the city.

(7) *Athabaska Palaeozoic Ground Water Province*—This province is largely uninhabited, and the ground water supplies obtained are largely from shallow wells in the glacial drift. The area is underlain by Palaeozoic limestones that contain water in their upper weathered surfaces.

(8) *Mackenzie Basin Palaeozoic Ground Water Province*—Centers of population in this province are confined almost wholly to the shores of the rivers and lakes. Most of the ground water supply is derived from the glacial drift. The bedrock consists of shales, limestones, dolomites, quartzites and local beds of salt and gypsum, and the water that occurs in the aquifers in these rocks would show a wide range in mineralization.

(9) *Small Palaeozoic Outliers*—Small areas underlain by Palaeozoic rocks occur at Nicholson Lake, N.W.T.; Nipissing, Temiskaming and Pembroke in Ontario; Lake St. John, Echo Lake and near Quebec City in Quebec. In all of these areas water is derived from shallow wells in the overlying drift and from aquifers, faults or fractures and bedding planes that occur in the Palaeozoic limestones. In the Temiskaming outlier, artesian supplies are obtained from the limestone.

III. Cretaceous Areas of the Great Plains—(1) *The Central Plains Cretaceous Ground Water Province*—Most water supplies in this large province are obtained from the glacial drift that covers most of the area. Over much of the area the glacial drift is overlain by clays that were deposited in numerous glacial lakes formed durring the retreat of the ice and in these areas it is necessary to penetrate the clay to obtain water. The water from the drift is generally very hard. Flowing artesian wells occur in the drift area over much of southern Saskatchewan. Where insufficient water is obtainable from the drift, supplies can generally be obtained from aquifiers in the underlying Cretaceous beds. These generally yield soft and rather highly mineralized water. Much of the area in southeastern Alberta north of Milk River is served by artesian wells that tap the Milk river sandstone which is one of the best aquifers in the district. Throughout most of this district the Cretaceous beds have a gentle westerly dip and the increase in elevation westward does not permit the existence of flowing artesian wells.

(2) *Great Bear Lake Cretaceous Ground Water Province*—This area is only very sparsely inhabited and therefore requires small supplies of ground water, most of which can be obtained from the glacial drift. The underlying bedrock consists of shales and interbedded sandstones of Cretaceous age that contain aquifers from which

ground water supplies can be obtained if required.

(3) *Good Hope Cretaceous Ground Water Province*—This area is confined to the Mackenzie River Valley where there is an ample supply of water. If necessary, ground water can probably be obtained from the beds of sandstone that occur in the Cretaceous shale or at the contact of the Cretaceous shales and the underlying Palaeozoic limestones.

(4) *Mackenzie River Delta Mesozoic Ground Water Province*—Much of this area was submerged by the sea and is covered by marine clay. Water of good quality may be expected in the alluvial deposits that occur beneath the marine clay or, if the drift is absent, from aquifers in the underlying bedrock.

(5) *Arctic Islands Mesozoic Ground Water Province*—Rocks of Mesozoic age occur in a number of the islands of the Arctic Archipelago including Prince Patrick Island on the west and Ellesmere Island on the east. These rocks contain porous sandstone aquifers from which, if required, water supplies could be obtained from beneath the frost line.

(6) *Moose River Basin Cretaceous Ground Water Province*—Small areas of Cretaceous rocks occur in the Moose River basin. These areas are overlain by glacial drift or marine clays in which occur aquifers that yield ample supplies of water. Where these are thin or absent, ground water may be obtained from the sands in the Cretaceous shale or at the contact between the Cretaceous and underlying Palaeozoic rocks.

IV. Tertiary Areas of the Great Plains—(1) *Southern Saskatchewan Tertiary Ground Water Province*—Considerable amounts of ground water can be obtained from the drift and from the Tertiary sandstone which underlie the higher elevations extending from Turtle Mountain in Manitoba through the Wood Mountain-Willowbunch area of southern Saskatchewan and the Cypress Hills area of southeastern Alberta, the amount derived from the aquifers being dependent on rainfall, the extent of the catchment area and the dip of the beds. In the localities where the Tertiary deposits are thin or badly eroded, the ground water conditions are unfavorable.

(2) *Alberta Syncline Tertiary Ground Water Province*—Satisfactory supplies of ground water in this province can usually be obtained from the glacial drift and from the underlying Tertiary sand or gravel which are generally very porous. These rocks occupy the central narrow trough of the Alberta Syncline, and their catchment area is slight, so that the ground water supplies from wells drilled in this belt are sometimes small.

(3) *Norman Tertiary Ground Water Province*—This area is located in the valley of the Mackenzie River where it is not necessary to rely on ground water supplies. The Eocene sandstones and conglomerates are very porous and, providing that water enters them, they should yield good supplies. Supplies should also be obtained from the unconformity that occurs between these Tertiary beds and the underlying Palaeozoic limestone.

(4) *Arctic Islands Tertiary Ground Water Province*—Small isolated areas of Tertiary rocks occur at several of the Arctic Islands as at Ponds Inlet. As ample water supplies are available from the surface sources, it is not likely that the aquifers in these Tertiary beds will be used as a source for ground water supplies.

Appalachia Structural Unit

The Appalachia structural unit embraces that part of Canada and Newfoundland lying to the east of the fault that extends from Lake Champlain to Quebec, and thence down the St. Lawrence River pasing south of Anticosti Island and through the Strait of Belle Isle. This structural unit consists of rocks ranging in age from Precambrian to Mesozoic which are so highly folded and faulted that they do not lend themselves to a subdivision such as followed with the Laurentian structural unit. For ground water purposes this structural unit can be best subdivided into the following three ground water provinces. As the first of these provinces consists mainly of small isolated areas of igneous rocks and the second and third are separated on a structural rather than a stratigraphic basis, these ground water provinces are not shown on the accompanying geological map (Fig. 3).

(1) *Precambrian and Igneous Ground Water Province*—A large part of Appalachia is underlain by dense Precambrian igneous and metamorphous rocks and by later intrusive rocks in which water is found only in joint planes and fracture zones. In these areas the ground water supplies are largely obtained from aquifers in the glacial drift or at the contact of the glacial drift and the underlying bedrock.

(2) *Deformed Palaeozoic Ground Water Province*—Over much of Appalachia the early Palaeozoic rocks have been highly folded and faulted and the spaces between the grains of the sandstones have been so completely filled by the deposition of calcareous and siliceous cement that they have been rendered impervious. In these areas the ground water supply derived from the rocks is very meager, and the chief sources of ground water in the areas are aquifers that occur in the glacial drift or in recent alluvium.

(3) *Undeformed Palaeozoic Ground Water Province*—The central part of Appalachia, covering much of eastern New Brunswick, northern Nova Scotia, Prince Edward Island and the Magdalen Islands, is underlain by Carboniferous or later rocks that are very little disturbed. These rocks consist chiefly of sandstones, shale and conglomerate, and from them good supplies of water can generally be obtained. The best source of ground water, however, in this region also is the glacial drift. In the low coastal areas the drift is generally overlain by a stratum of marine clay which results in flowing artesian wells at a number of localities along the coast, the contained water being derived from intake areas of these aquifers on the higher ground.

Cordillera Structural Unit

The Cordillera structural unit differs so materially from the other two structural units in respect to topography, climate and geology that it has not been subdivided into ground water provinces. Most of the area is mountainous and, except in a few scattered areas along the main valleys, it is largely uninhabited. The heavy rainfall and the high relief generally provide ample supplies of surface water in the form of rivers, lakes and springs, and supplies of ground water are seldom required. Any consideration of its ground water supplies would be best dealt with under the five physiographic sub-provinces as listed in the previous section and indicated by numbers 1, 2, 3, 4 and 5 of the Cordillera area,

shown on structure section A-B of Fig. 3. The bedrock has been rendered so impervious, and the strata are generally so steeply inclined and faulted as a result of mountain-building forces, that the runoff is rapid and bedrock consequently is not a source of water supply. Such supplies as are obtained from bedrock are derived almost entirely from solution channels that follow the faults and joint planes. The main sources of ground water are alluvial deposits which are generally very porous; these either carry abundant supplies of water or are altogether dry, depending on their position relative to the intake areas and to the bedrock topography.

L-39 Modification on Hose Couplings

Restrictions on the use of copper and copper base alloy in the manufacture of 1½-in. and 2½-in. fire hose couplings have been removed by the WPB.

The Rehabilitation, Cleaning and Sterilization of Water Wells

By Loren E. Blakeley

Cons. Civ. Engr., Santa Ana, Calif.

Presented on Oct. 25, 1944, at the California Section Meeting, Los Angeles, Calif.

REHABILITATION of a well after it has collapsed might be considered as a technical or mechanical problem, but in the long run the matter of economics governs and the engineer's proposals to correct past mistakes may be sidetracked by the elements of chance in providing a sure cure. This makes it all the more desirable to eliminate unknown hazards from future operation costs of water companies, both in construction and in sanitation matters.

During the 1930 dry cycle, wells were drilled by many companies in a frantic rush to keep production ahead of consumption. Investigation of some of these—three 26-in. diameter wells of the Santa Ana Valley Irrigation Co. and other wells—was begun in September 1937 and work was completed in October 1938. The wells have been in regular use since that time with no recurrence of trouble or production of sand or silt, so it is believed that now the work can be said to be satisfactory.

Salvage Problems

In Well 20, a 26-in. diameter well, 1,211 ft. deep, drilled in 1935 at a cost of $14,874, the yield fell off to such an extent during its six-months' shutdown period in the fall of 1937, at which time it was sand pumped, that it drew air through the pump when started for an efficiency test in May 1938. Due to low setting of the pump bowls a drawdown of 151 ft. with a yield of about 2,250 gpm. was obtained for a few minutes until the motor was shut off. The well was surveyed and an obstruction found at a depth of 576 ft. An impression block run down the casing showed clearly that an inner section of casing had opened at the seam and curled in. Later investigation showed that the break was caused by use of a vertical slot perforator without a seam finder, during the original perforation of the well.

Swages of proper diameter were obtained and the casing was driven out to a 25½-in. diameter at the point of incipient collapse. A 20-in. liner some 74 ft. long with steel-funnel type adapter was installed, resting on top of the old 20-in. casing. The liner covered up 38 ft. of unperforated fine sand and gravel in addition to 5 ft. of perforated casing located at the break. A number of "bumps" in the casing above the break were smoothed out and no serious trouble is expected from this well in the future. Results obtained on Wells 21 and 22 indicate the desirability of additional perforations in this well, both to increase the specific yield and to prevent further possibility of unbalanced pressure inside and outside the casing.

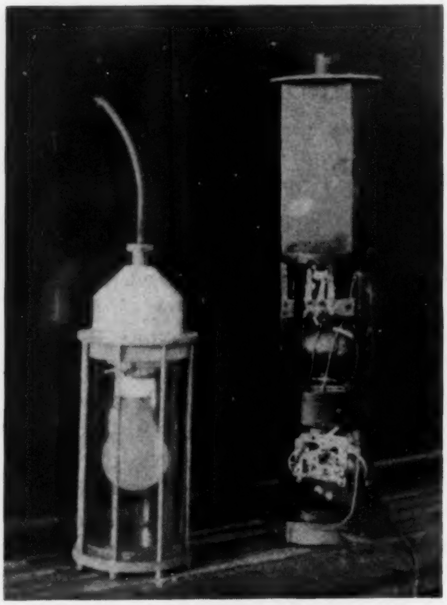

FIG. 1. Bottom Hole Camera and Electric Light

The old tuberculated and pitted 14-in. diameter pump column in this well was one of the first in southern California to be given a spun coal-tar enamel lining. Several brands of material were used and when the pump column is pulled for pump bowl replacement in another year it will be possible to get an eight-year experience record on the condition of the inner and outer layers of coal-tar enamel. It is now standard practice when a company pump is pulled to sandblast and enamel completely the column and tubing. Pressure test plugs were installed at the top and bottom of several pump columns, which were both of the enameled and of the old rough pipe type. Head-loss measurements over a period of several years show a saving of approximately 1 ft. per 100 ft. of column with a discharge of 2,500 gpm. by use of coal-tar enamel. Depreciation charges were cut in half, at a considerable saving in the annual cost of water.

Collapsed Casing

Well 21, a 26-in. diameter well for 620 ft., with a string of 20-in. casing extending below that to a total depth of 1,250 ft., collapsed in April 1937 on its first test run for the season. The well had been completed and put into operation late in the 1936 pumping season when the water table in the vicinity was normally low and further depression was caused by excessive drawdown on nearby wells. Yield of the well dropped from 2,350 gpm. when turned into the system on July 20, 1936, to 2,190 gpm. during September to December 1936 at the close of the pumping season. During this period the average drawdown of the water table below static level was in excess of 100 ft.

During its development the well ran some sand and silt. When the pump was pulled in January 1937 some 233 ft. of material, amounting to about 19 cu.yd., was removed from the lower string of 20-in. casing. No coarse material was encountered during the first sand pumping. When the well was tested by company employees after sand pumping its yield had dropped to 2,000 gpm. with a drawdown of 115 ft. On May 26, 1937, when the pump was started for a trial run and efficiency test by the Southern California Edison Co.'s engineers, the casing collapsed at a point about 340 ft. below the ground surface.

By September 1937 the well had for all practical purposes been abandoned and its capital cost of $16,230 was considered a total loss. Subsequent tests showed that the well would have produced about 200 gpm. from perforations above the collapsed section with

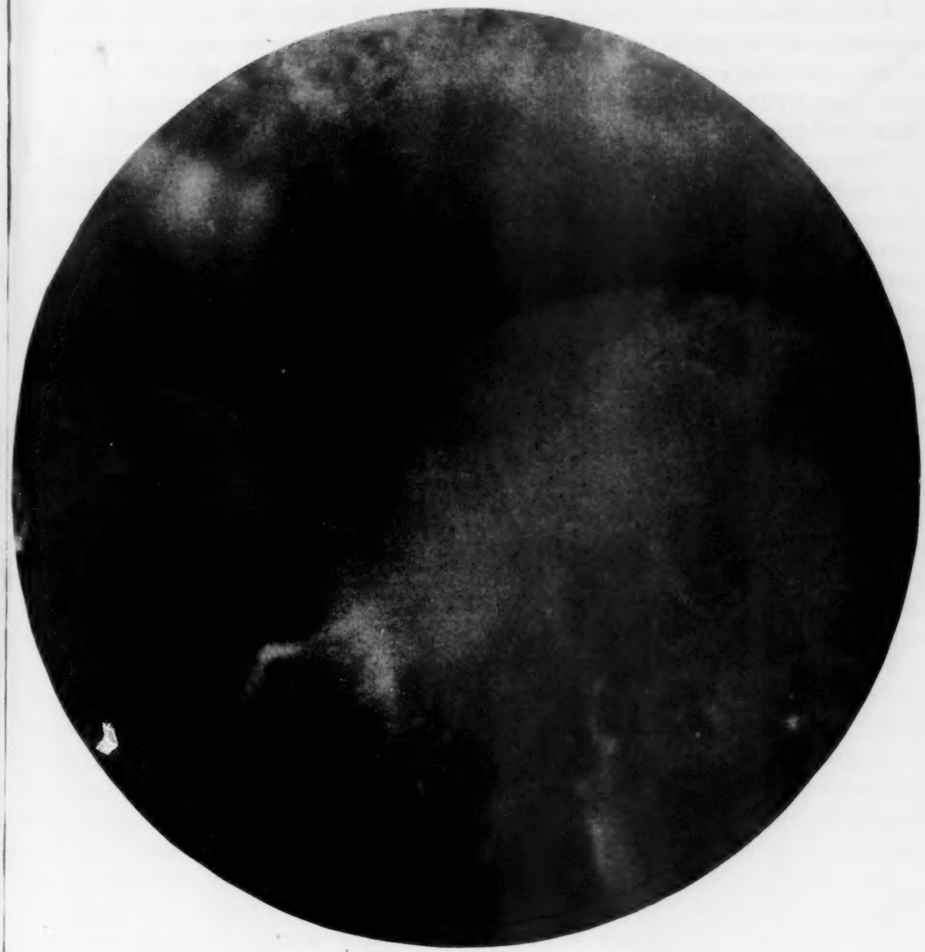

FIG. 2. Collapsed Inner Sheet of Casing at Depth of 340 ft.

drawdown of 25 ft., and that it thus represented an investment of over $81 per gpm. yield.

It had been found impossible in May 1937 to lower a 13-in. sand bucket into the well below a 343-ft. depth, and when sent down alone the 6-in. diameter set of jars apparently went down outside the casing about 8 ft. farther and brought up sticky yellow clay. Standard engineering practice for surveying the plumbness of the well disclosed no difficulty until a depth of 341 ft. was reached. At this point a 25-in. diameter cage hung up. At 343 ft. a 20-in. cage hung up and at 350 ft. it was impossible to get a $6\frac{1}{2}$-in. cage through the hole. Later on it was found possible to put a 4-in. cage through two separate holes, one near the east and the other near the west side of the hole. Weights were run to a depth of more than 800 ft. where it was found from subsequent work that gravel up to 6 in. in diameter had filled the 20-in. casing.

At this time it was deemed desirable to determine the condition and nature of the break more accurately than had been done by the use of an impression block and the varying-diameter cages. A "Bottom Hole" camera, used in the oil fields with great success by the Eastman Oil Well Survey Co. of Long Beach, was adapted for use under high water pressure, and photographs of the collapsed section were made under more than 160 ft. of water. On the second run an electric light was lowered into the "pair of pants" formed by the collapsed casing, and a silhouette view showed clearly the existence of two separate entrances to the open casing below the break. Figures 1, 2 and 3 show the camera and the photographs of the collapsed section of the 26-in. diameter, double, No. 8, hard, red steel casing.

Subsequent to this, the Roscoe Moss Co. of Los Angeles was engaged to swage out the well. The two holes were gradually enlarged horizontally without further serious disruption of the casing by successive swages varying from 6 in. to $25\frac{1}{2}$ in. in diameter. A liner 22 in. in diameter, with three 24-in. diameter steel brace rings, was driven into place covering the bad area from 334 ft. to 364 ft. deep. During swaging operations, sand had filled the casing to a depth of 585 ft. below ground level. Sand pumping of the upper 620 ft. of 26-in. casing brought up sand with a very small percentage of gravel of sizes up to $\frac{1}{2}$-in. diameter, the largest of which could come through the $\frac{1}{2}$-in. × 4-in. long vertical slots which constituted the original perforations of the well. The difference between this material and that brought up later from near the bottom of the well shows that the collapsed section, which had let in 6-in. diameter rocks and gravel, is effectively protected by the steel liner.

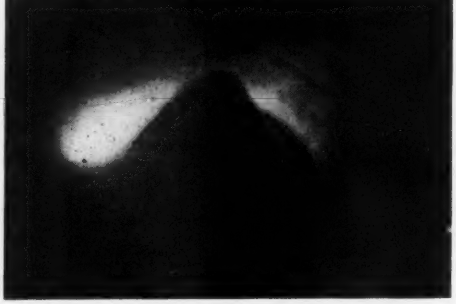

FIG. 3. Silhouetted View Showing Nature of Two Openings
Camera at 340 ft., Light at 358 ft.

Improvement of Yield Characteristics

To determine the relative water-yielding properties of the upper 600 and the lower 650 ft. it was deemed desirable to test the well before additional perforations were made. A specific yield test of the upper 600 ft. proved that a yield of 550 gpm., or 6.7 gpm. per ft. of gravel in 83 ft. of the supposedly best water-bearing strata in the well could be developed from the vertical perforations with a 34-ft. drawdown.

A study of well logs and performance data on nearby company wells indicated that additional perforations should yield more water. It was decided to perforate 40 ft. of water-bearing "sand" and gravel above the liner. An additional yield of 1,250 gpm., or 31.2 gpm. per ft. of perforation, was secured with a 34-ft. drawdown. The horizontal louvre perforations thus show 366 per cent increase in yield per foot of perforated 26-in. casing over and above the yield obtained from vertical slot perforations in this part of the well. The combined yield is 327 per cent of the original with a 48-

per cent increase in length of perforated casing. An unknown but appreciable further increase in yield could have been obtained from about 60 ft. of water-bearing strata which exists below the liner and above the 20-in. casing, but development costs on a tion. Figure 5 shows the type of perforation made by this machine in a section of well casing. It can be readily seen how the flow of water is generally upward into this type of perforation, since the gravel screen is made below the extended louvre. Because all sand

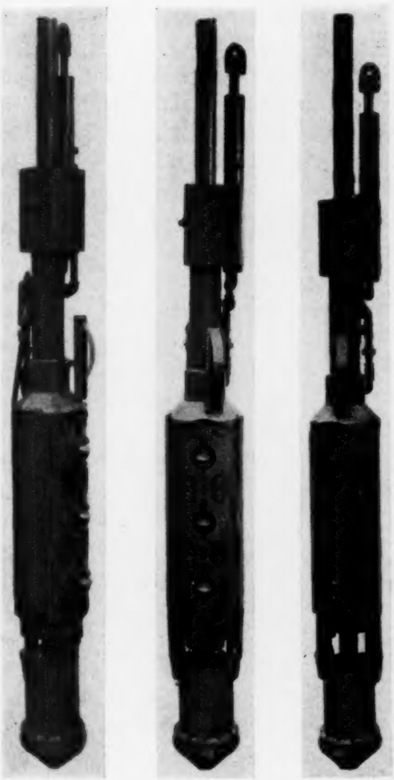

Fig. 4. Moss Hydraulic Perforator Showing Pistons and Cutting Blades in Both Extended and Retracted Positions

Fig. 5. Section of Casing With Moss Horizontal Louvre Perforations

perforator which would go through the 22-in. net diameter liner and expand to fit the 26-in. casing made the job prohibitive.

Figure 4 shows three views of the Moss hydraulic perforator, one with the blades extended and the others with blades and pistons in retracted posi-

and fine gravel particles must come to rest and be forced upward before entering the casing, it is possible to develop a screen and capillary channels in sand of 1-mm. diameter. A very small percentage of larger-sized gravel will permit wider openings and less entrance head loss. Wells thus per-

forated develop much more rapidly, since churning the sand bucket soon develops a screen and there is no tendency for fine sand and silt to run down the casing from higher levels.

After the upper half of the well was ready for operation—a salvage job of considerable difficulty in itself—the most difficult part of the job still remained. An unusual break in a set of annealed jars occurred on the last pass through the collapsed section with a $19\frac{5}{8}$-in. diameter smooth swage, and the heavy steel casting kept on going. After the collapsed 26-in. casing had been finally driven out and the 22-in. inside diameter liner driven into place, the upper part of the well developed and tested, a two-month's fishing job began. This commenced by placing a $3\frac{1}{4}$-in. dart in a slot only $3\frac{1}{2}$ in. wide on the high side of the swage some 794 ft. below ground. (One dart was lost after making contact with the slot on the low side of the swage.)

In lieu of installing a proper adapter between the 20- and 26-in. casings during original construction, the 20-in. casing had merely been belled out by a large swage. This was later found to have produced a loose funnel consisting of a split ring of 20-in. casing about 12 in. high, and several smaller pieces bent back toward the 26-in. casing. The ring went down the 20-in. casing ahead of the swage and a number of the smaller pieces fell in on top when the swage was nearly out of the 20-in. casing. As a result the swage was completely locked into the casing. A month of careful jarring finally pulled the 20-in. casing apart below the swage and about 10 ft. below the 26-in. starting shoe, which was luckily still in a clay stratum. The job then became a mere routine one of cleaning out the hole, installing and connecting new 20-in. casing with a spring steel "grass skirt" adapter, and getting the well ready for production. When the swage was finally cut out of the casing it had developed a $\frac{1}{2}$-in. wide crack several inches long and it would have been only a relatively short time until the spear would have pulled out. Figure 6 shows the results of this unusual fishing job.

At this point tribute should be paid to the driller, whose patience and skill in reading vibrations in the cable played so great a part in the success of the rehabilitation job. The engineer can theorize about the shape and cause of the break, the directors can gamble a bit with some money in an endeavor to salvage past losses, the best rig and equipment may be furnished, but the best driller in the country is necessary to patch an egg shell several hundred feet underground.

Following perforation and testing of the 26-in. casing, the well was cleaned to the bottom. Sixty feet of sand and gravel in the 20-in. casing, which had been considered too fine to perforate with a vertical slot perforator, was made available by the Moss horizontal louvre hydraulic perforator. An additional yield at a 34-ft. drawdown of 600 gpm., or 10 gpm. per ft. of perforated 20-in. casing, was developed by these perforations as compared with 400 gpm., or 5.8 gpm. per ft., obtained from the original vertical slot perforations in 69 ft. of coarse gravel. A total increase of 100 ft. of perforated water-bearing strata in the entire well, or 66 per cent of the original 152 ft. of perforations, gave an increase in available water of from 950 to 2,800 gpm. or 195 per cent more water than originally developed with a drawdown of 34 ft. After rehabilitation in September 1938, the well was put into

FIG. 6. Remains of Original 20-in. Adapter and Swage After 30-Day Fishing Job

production at the rate of 1,800 gpm., and production gradually increased to 2,800 gpm. as there was no sand or silt evident in the water. Due to a rise in the water table in the area it has been producing during 1944 at the rate of about 2,700 gpm. with 20 ft. less lift than when it was rehabilitated in 1938. Rehabilitation of this well represents a saving of at least 80¢ per acre-ft. of water pumped at the present rate of yield, based on minimum block power rate savings of 5 mills per kwhr. and a pump lift 80 ft. less, due to flattening of the specific yield curve. This saving is an appreciable percentage of the average total charges to stockholders of approximately $5.00 per acre-ft. or the average production costs of wells in this vicinity which amount to $3.26 per acre-ft.

The value of the job as a capital improvement can be seen in the following figures: the original cost was $16,230, of which the upper 600 ft. cost approximately $7,000 and the lower 650 ft. of 20-in. casing cost $9,230. Surveying, swaging, installing the liner and sand pumping in the 26-in. casing cost $1,850. Perforating 20 ft. of 26-in. casing cost $370, making the capital charges for the upper 600 ft. a total of $9,220. To open up the 20-in. casing, remove the swage and install the new section of casing and adapter cost $1,860, which together with new perforations in 60 ft. of casing costing $690, made a total cost of $11,780 for the bottom 650 ft. of the well. The final cost of the rehabilitated well was thus some $21,000 without engineering charges. When yield from the continental, or recent, and the older marine formations is compared with the cost of drilling, it appears that the lower water is quite expensive and that its development in some instances would not be justified.

Profitable Reperforating

Well 22, a 26-in. diameter well with secondary strings of 20-in. and 16-in. casing totalling 1,050 ft. deep, was completed in 1937 at an approximate cost of $16,800. On test it developed so little water that some question was raised as to the thoroughness of the perforating job. Accordingly, the original driller returned to the job and made a very thorough swabbing test and development of each perforated stratum. Results of this test proved conclusively that perforations were made as specified and that the particular strata and vertical-slot type of perforations in the well were thoroughly developed. About 90 gpm. additional yield was obtained when the pump was reinstalled after swabbing. A complete specific yield test of Well 22 on May 11, 1938, showed maximum production of 1,850 gpm. with a drawdown of 150 ft. below static water level. Due to the nature of the gravels

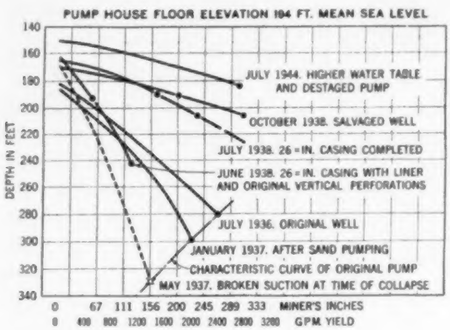

FIG. 7. Specific Yield Curves of Well 21 Santa Ana Valley Irrigation Co., Orange, Calif.

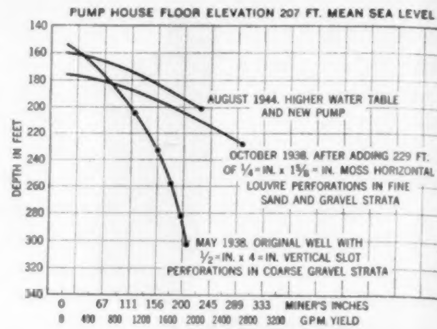

FIG. 8. Specific Yield Curves of Well 22 Santa Ana Valley Irrigation Co., Orange, Calif.

perforated, or other undetermined causes, the yield curve broke rather steeply after the drawdown reached 50 ft. The safe yield of the well at 40-ft. drawdown was only 900 gpm. The entire 26-in. casing was within 2 in. of being vertical and due to luck in the original perforating job (done in riveted casing without a seam finder) there were no blemishes in the 26- or 20-in. casings.

A study of the well log and samples of material brought in by swabbing, together with information obtained by questioning all persons connected with drilling the well, indicated that additional perforations in material considered too fine to cut with either the $\frac{1}{2}$- × 4-in., or $\frac{3}{8}$ × 4-in. vertical-slot perforator commonly used could safely be done, and that considerable additional water could be developed. This work was completed in October 1938 and the well put into production near the end of the pumping season.

This well as originally perforated had 2,471 sq.in. of perforations, or 13.65 sq.in. per ft. of perforated casing totalling 181 ft. Additional perforations at the average rate of 13.05 sq. in. per ft. of casing in 229 ft. of casing added 2,989 sq.in. of openings to fine sand and gravel strata.

In this well the safe yield was increased from 900 gpm. to 2,200 gpm. with a drawdown of 40 ft., while the apparent economic yield with 25-ft. drawdown was increased from 600 to 1,800 gpm. At this latter conservative yield the saving in drawdown of more than 100 ft. can be credited entirely to additional horizontal-louvre-type perforations in fine water-bearing sands. The annual power bill saving based on six months' use of the well per year will be about $1,300, considering all savings to be in the lowest power block of 5 mills per kwhr. This is equivalent to a 5-per cent yield on an investment of $26,000. Twelve hundred dollars was the total cost of building special adapters for use with a regular 20-in. perforator in the 26-in. casing, making perforations in 229 ft. of casing opposite fine sand strata, undercutting old perforations opposite clay strata below good gravel and thoroughly developing the rehabilitated well. The method of flattening the specific yield curve by additional perforations offers distinct financial return if successful. It is more certain of success if the wells

have been drilled fairly recently and have not been over-pumped. Figures 7 and 8 portray graphically the various characteristic curves of Wells 21 and 22.

Work was done about a year later on Well 11, a 20-year old nearby well of rather erratic performance. After several incipient collapses, evidenced by bulges into the casing, were smoothed out, additional vertical-slot perforations were carefully placed between the old ones in the lower string of 16-in. casing. Additional horizontal-louvre perforations were made in the upper strata and the well was redeveloped. Specific yield curves made before and after the work indicated a loss of 20 or 30 gpm., instead of the high percentage gain shown by the other wells. Results on this well were inconclusive, but indicated bleeding from a perched stratum into the lower major water-bearing strata, and probably a carbonate cementation of sand and gravel particles within a large portion of the cone of depression around the well, caused by drawdown of 100 to 125 ft. during many years of operation. Due to the high cost and the uncertainty of success, acid treatment of the perforated strata or shock treatment to break new channels through the gravel was not attempted, and the well is maintained as a standby.

During this period Well 17, which had, on some other occasions of low water table, pumped air, suddenly dropped off in production. It too had been heavily over-pumped for a number of years. The well was surveyed with a variable-diameter cage but no breaks could be found. Comparison of the several wells indicated that at certain strata which had too small a percentage of gravel to make a suitable screen outside the vertical-slot perforations, an excessive amount of silt ran into the well, leaving a considerable cavity underneath rather soft clay strata. Excessive drawdown probably pulled out nearly all water support and clay settled down on the gravel cone, thus effectively shutting off yield from the affected stratum.

Muddy water and lowered yield resulted when clay fell while the pump was running. In other wells the gravel stratum was sealed off by clay spalling off over the winter shut-down period. Due to improper pump bowl setting and capacity, unbalanced pressures too great for the weakened casing occurred when the pumps were started with the water table at its spring peak. Replacement pumps are now purchased to fit the characteristic curves of each well. Pumping levels in general are being maintained above sea level, both to protect the basin and to equalize pumping costs. Column lengths are kept as short as feasible to prevent future collapse if clay strata should again close off the water.

Cleaning and Sterilization of Water Wells

Over the past hundreds of thousands of years, nature has blessed southern California and much of the rest of the state with underground basins or river channels from which potable, palatable and sterile water can be drawn in large quantities. This is a condition which should be maintained for all time. These underground reservoirs have coverings of soil, sand and gravel, varying from a few feet to several hundred feet. Without the filter effect of such cover the underground water would be as foul as the surface sloughs which

drain off from some of our dairy areas.

Basic factors affecting the rate of spread of pollution, both bacterial and chemical, have been covered quite thoroughly by others (1). Contamination of pumped water by pathogenic organisms has been the principal consideration of health departments in formulations of rules and procedure for proper construction of wells. The recently published U.S. Public Health Service *Sanitation Manual for Public Ground Water Supplies* (2) is a fine attempt to deal with a practical problem in an academic manner. If it confined itself to a treatise on the principles involved and left proper practice methods to more practical men whose lifetime work has been to produce water of proper quality and sufficient quantity to meet the consumers' needs, there would be a much better acceptance in the field. For example, practical drillers, knowing the extent of polluted upper strata which must be shut off, are not inclined to agree that sprinkling a little chlorine solution on already washed gravel is the answer to the sanitation of a gravel-packed well. No one can tell when the outer casing will rust through or be eaten out by electrolysis. Regulations should provide for the maintenance of the highest quality of underground basins, rather than specify arbitrary types of construction over which there can be legitimate differences of opinion as to effectiveness.

Drillers normally seal off surface water in areas of high water table, but there is practically no inspection to see that water wells are maintained in proper condition throughout their useful life, and to be certain that they are properly plugged when abandoned. Large producers are generally cognizant of their responsibilities and take all reasonable precautions to provide and maintain proper sanitary conditions around their water systems.

The state health department in general has no jurisdiction over concerns with less than 200 services or from 800 to 1,000 population served. Inspection of utilities and individuals in this classification in general come under the jurisdiction of county health departments. Los Angeles County has developed a program to meet the needs of its highly developed areas which calls for a drilling permit to be granted by the county health department for all new wells. Bacterial examinations are made regularly for all producers with four or more services and special tests are done when the need arises. Among other things this tends to impress upon the owner, driller and operator the need for proper sanitary precautions.

Pollution Problems

In general a well is constructed of materials free of pathogenic organisms. This is particularly true of the California or "stovepipe" type of construction. Rotary drilled wells, where mud, water and sometimes other crack-filling material from outside sources are forced into the soft gravel strata to maintain the hole until the casing and gravel are installed, offer a much greater opportunity to pollute or contaminate underground water strata. "Mud engineering" is a relatively new development in rotary drilling. The principles are just as important in water well drilling as in its more expensive younger brother, the drilling of deep oil wells. Details of practice in this field can be found in a recent issue of *Engineering and Science Review* (3).

The task of cleaning and developing such wells is more complicated than developing an ordinary well. The mud should be thinned down before gravel is installed, but there is no sure way of cleaning out polluted material. Development of the well breaks down the mud wall in water-bearing strata, but there is no assurance of adequate flow in the gravel pack around the casing opposite the clay strata. Better drilling practice calls for a continuous string of perforated casing below the top water-bearing strata. For the sake of saving a few dollars in the cost of casing, many wells have been constructed with only partially perforated casing, and in such wells the problem of cleaning out the mud is practically hopeless. If polluting material is once put into such a well the cost of correcting the situation is exhorbitant. Fortunately, water well drillers believe in their product and normally take due precautions to protect the sanitary quality of underground waters. Unfortunately, some concerns with wastes to dispose of are prone to take the cheap and easy way out of their disposal problems, and water works operators are forced into expensive construction and operation practices to correct mistakes of the past and present over which they have no control.

Spreading Wells

In this arid locality, water conservation has a popular appeal. All measures to secure it have their ardent supporters. The programs run the gamut from use of semi-treated sewage water for irrigation purposes and spreading on waste lands to the practice of drilling or digging wells and pits down into water-bearing strata for the purpose of spreading flood wastes at the infrequent times they occur. Any spreading ground acts much as a filter in a domestic water purification plant. Sediment in the water fills the larger pores between grains of sand in the pervious material; then on top of this are caught the larger micro-organisms. As a deck is built up the almost invisible diatoms and bacteria, if any, are caught and held until the filter surface is broken up by cultivation or by natural means.

When an underground water-bearing stratum is inoculated with dead organisms and silt, it merely plugs up as sufficient material is forced into it. When, however, a water stratum is given a dose of living organisms it is possible for some forms to live and multiply and pass on down the water table surface to reappear at wells some distance from the point of contamination or pollution. For this reason alone, water spreading is advisable at points in the watershed where distance to ground water is the greatest. In no event should water containing live organisms, pathogenic or otherwise, be introduced directly into a water-bearing stratum. It was necessary to redevelop a number of water wells used for spreading purposes by the city of Los Angeles (4). The process is costly and sometimes unsatisfactory. At Calwa, Calif., ground water contaminated by cesspool waste was pumped from a well 1,000 ft. away.

It is no matter of civic pride in southern California to be able to point out that food processing plants in the industrial city of Vernon now have to install a contamination string to shut off all water-bearing strata above 600 ft. to be assured of water free from pollution caused by dumping of refinery and other industrial wastes into

sewer wells. Chemical pollution is a much more serious problem than ordinary household sewage contamination.

MacMurray (1) shows the travel of chemicals in underground strata amounting to about 300 ft. in about 2½ years. At least three wells located from 3 to 5 mi. from the old center of industrial pollution are now producing water with a "turpentine" flavor which does not respond to any known treatment. Another domestic water well located in the Vernon district has been polluted with a disagreeable black waste which ate through the well casing above the water table. Shallow wells in the area have long since been abandoned, but no one knows whether they were properly plugged or not. All odds are against it, and we may expect bleeding from the upper strata, which are replenished by rainfall, into the major aquifers until water from a huge underground basin becomes unfit for human consumption. The economic loss caused by this condition should not be minimized as there are several service areas therein with absolutely no other present source of water supply.

Organismal Pollution

There are a few areas in southern California where *Crenothrix, Beggiatoa* and some other organisms have for some reason found a foothold in underground strata. One inland occurrence has been discussed by Lynde and Ackerman of the Pasadena Water Department (5). In the Coastal Basin near the Inglewood fault zone several wells are affected, and in some instances the deeper strata are worse than the shallow. Continuous treatment of the water is required, as all attempts to sterilize the area surrounding the wells have so far failed. Proper treatment is a serious item of production cost wherever the problem occurs.

The general remedy is palliative and consists of heavy chlorination of the water. In some instances a rubber hose is run down the well to the pump intake. This method was successfully used at Santa Monica to maintain pump efficiency by preventing growth in the runners and bowl. Conditions in the well are now unknown since the city has been using softened Colorado River water from the Metropolitan Water District's system for the past three years.

The California State Health Department issued recommendations in 1942 for sterilization of wells in flooded areas which provide for use of chloride of lime or powdered hydrated lime in sufficient quantity to permeate thoroughly the water from top to bottom of the well. After standing for 24 hr. it is then recommended that no water be used until five to ten times the volume of water in the well has been pumped out. Dilution, of course, is a great factor in furnishing a satisfactory product after surface water has run into a well, and it is extremely difficult to make set rules to cover all conceivable conditions, types and degrees of pollution or contamination.

Sterilization of a Gravel-Packed Well

Repeated confirmed coliform samples from an army air base well near Indio caused some concern and two attempts were made to sterilize the well. This well had a contamination string of 10-gage casing, 26-in. in diameter and some 40 ft. in depth. Inside this was a 750-ft. string of 12-in. 8-gage casing perforated from 220 ft. to 730 ft. Above the top perforation there were 12 ft. of gravel and sand, and 92 ft. of

sand interspersed between strata of sand and clay. The top 265 ft. of perforations are opposite a stratum logged as sand and clay. Some 1,550 gal. of 3,450-ppm. chlorine solution were poured into the gravel pack and for a time a chlorine residual of 2 ppm. was obtained at the pump. This residual ceased shortly before the gravel pack refused to take any more solution (bridging of gravel and rotary mud or clay probably occurred at some point above the perforations). Twenty-four gallons of 3-per cent chlorine solution were then poured directly down into the casing and the well was then surged repeatedly until a residual of more than 200 ppm. was obtained. The well was then allowed to stand for 38 hr. before being used. Samples taken at this well after sterilization was complete, and again six months later, showed a very low plate count and no coliform organisms on the final reports. The army, however, continued to use a chlorinator to maintain the arbitrary 0.4-ppm. requirement of the U.S. Public Health Service.

Yield of the well was 400 gpm. so it can be seen that about 4-min. production was necessary to plug up the gravel pack above the perforations. The cause of the contamination was not determined. Consideration of the above details indicates the difficulty of securing complete sterilization of such a well if polluted strata exist or if any improper materials were used in its construction.

All of such treatment is expensive and of questionable effectiveness without long-continued laboratory control.

Industrial Pollution

Pollution of underground water is, however, a problem which faces every water works in southern California. The growth of heavy industry, with pickle vats, plating works, oil residue, wash water of all sorts, together with existing citrus waste disposal and many other chemical processes, are overloading existing sewage disposal works. The trend is definitely toward more of such pollution of underground basins and unless prompt measures are taken to make technical studies, watershed by watershed, and to provide adequate disposal facilities for all types of industrial wastes, the time will come when water works operators will be faced with a problem of reclaiming second-hand water for drinking purposes.

In 1943 about 10 per cent of the orange crop was set aside for juice by government order. The heavy concentration of orange waste in a few plants has caused disruption of normal sewage treatment and has resulted in dumping of the refuse in irrigation canals, orchards and dumping grounds. Such organic acid wastes, under proper soil-laboratory control, are good for alkaline soils, but when the disposal dumps are large and used for many years a threat exists to the quality of underground water. In one recent instance, the operator of a sewage disposal plant (whose effluent is spread on a gravel plain downstream from the plant) complained that drinking water from a shallow well at the plant tasted like orange juice. Examination of the area later on disclosed a long abandoned well under a nearby orange dump. Fortunately there are no domestic wells near the effluent spreading grounds.

Economic Loss

The economic loss to the community by permitting such conditions to occur far outweighs the cost of proper pre-

vention. Water in a surface reservoir can be treated with various chemicals to restore it to potable condition in the event that polluting material is dumped into it. Samples can be taken readily at all desired locations and a complete study can be made before water is released to the consumers. On the other hand, try to visualize the difficulties and cost of determining the extent, both laterally and vertically, of pollution of a slowly-traveling underground body of water.

Those of us engaged in the water business on the coastal plain are between two fires. On the one hand, due to overpumping in some areas, there already is positive proof of encroachment of ocean water. Heavy industrial demands already have speeded up this saline encroachment, and the end is not yet in sight. On top of the ground, industrial wastes have been released into normally dry river beds and storm drains to relieve load on inadequate sewage disposal systems. These wastes have killed a number of cows who were inadvertently thirsty before the water had filtered down to the underground basin, been altered and diluted and pumped back up to the cattle troughs.

Proposed industrial development, extending as far as 60 mi. inland, will ultimately affect the cost and quality of all underground and the few surface streams between the mountains and the sea. Unless the quality of water resources of the area, together with the quantity, are soon intensively studied, with adequate laboratory and technical facilities and personnel, water users in the path of migrating bodies of underground water are apt, within the foreseeable future, to find their entire production capital wiped out. Sterilization of water wells is then in its larger aspect a preventative measure and one to be undertaken at its true source. Active work cannot begin too soon to determine the full extent and seriousness of the problem, and to devise measures to prevent the necessity of water treatment plants for every well in the country.

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Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34**: 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34**: 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene* (*British*); *C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research* (*British*); *I.M.—Institute of Metals* (*British*).

HEALTH AND HYGIENE

An Epidemic of 3000 Cases of Bacillary Dysentery Involving a War Industry and Members of the Armed Forces. C. H. KINNAMAN & F. C. BEELMAN. Am. J. Pub. Health **34**: 9: 948 (Sept. '44). On Sept. 12, '42, severe outbreak of intestinal disorder occurred in Newton, Kan. Pop. was 11,048 in 1940 incl. approx. 1200 Mexicans and 1400 Negroes. Public water supply derived from 8 drilled wells having avg. depth of 125', located 8½ mi. southwest of city and used by more than 95% of pop. Wells pumped to surface reservoir and water re-pumped from this reservoir into 2 high-service mains. Mains 12" and 14" in size and approx. 8 mi. in length before they connect to distr. system of city. Information received indicated that outbreak explosive in nature and geographical distr. uniform over entire city. Samples of water from city wells and distr. system taken at once. On Sept. 14, samples taken from deep wells showed no contamn.; however, those from various points on distr. system heavily contamd. City officials notified and chlorination of city water supply by means of emergency chlorinator at pumping station started. Hand-bills printed, advising citizens to boil all water used for drinking purposes and prohibiting sale of milk that had not been pasteurized. Air-raid wardens distributed hand-bills to every home in city. A.T. & S.F. R.R. immediately ordered to discontinue use of Newton water on passenger trains until proved safe for drinking purposes. City water supt. given instructions to shut off all public drinking fountains and immediately open fire hydrants and flush out water mains. Early studies of case reports revealed massive, generalized, sudden and severe epidemic of dysentery. Avg. case persisted for approx. 3 to 6 days. Weakness, nausea, vomiting, cramps in stomach, persistent diarrhea and occasional bloody diarrhea listed as symptoms. Only possible vehicle was water supply. San. engrs. checking systematically distr. system discovered following defects: (1) 7 cross-connections between public water supply and private sources of water. (2) 7 cross-connections between public water supply and sewerage system, plus 13 flush tanks in sewerage system in which water inlet below discharge level of tank, and large no. of basement ejector pumps located in private residences. After carefully checking all above cross-connections, apparent that source of contamn. had not been discovered. Epidemiological factors indicated that large amt. of contamn. introduced into water system at point from which it could be rapidly circulated through entire distr. system. This conclusion based upon following factors uncovered in epidemiological and lab. studies: (1) generalized distr. of cases, (2) massive infection of pop., (3) explosive nature of epidemic and (4) bact. anal. of water samples obtained over distr. system. On Sept. 18, 4 days after emergency chlorination started, tests showed that satisfactory chlorine residual being maintd. in all parts of city. Repeated satisfactory bact. anals. having been obtained, water released as safe, Sept. 19. Bit of information, which proved of extreme importance, received from Santa Fe Railway water dept. employee who said that sewer block had occurred at Mexican village on southwest outskirts of city about time that dysentery cases developed in city. On Sept. 20, inspection of water supply, plumbing and sewage disposal of Mexican village made by our san. engrs. Contrary to previous statements by city officials that no

change had been made to distr. system, further information uncovered fact that changes made on 2 main supply lines entering city at point close to Mexican village. It developed that on Sept. 7 an 8″ stub and valve removed and replaced with 20″ stub and valve. Water pressure was off 9 hr. while these changes made. On Sept. 8, found that 20″ gate valve had slipped and section of 14″ supply line again taken out of service for more than 3 hr., during which time 20″ gate valve straightened and permanently anchored. Work performed by private contractor, under supervision of city water supt. Investigation showed that service connection came from this 14″ main to Mexican village and supplied 3 frost-proof hydrants and two water-closets equipped with 12 frost-proof toilets. Frost-proof hydrant pits and each of pits under water-closets had drain connection to san. sewer, which had previously been blocked. Evidence that these pits had been filled with sewage so that it had covered drain openings in valves of frost-proof hydrants, and also drain connection in frost-proof toilets, still remained at time of our inspection. Hydrants were only source of water for Mexican families and water-closets used by approx. 112 persons living in village. In reconstr. of situation, when water pressure was off on Sept. 7 and 8, persons in village, attempting to get water, left them open; this, in turn, allowed sewage backed up in box to flow through drain opening into water main. Not unreasonable to assume that person attempting to get water and finding it shut off would leave valve open, allowing continuous flow of sewage through drain opening. That these valves were open brought out in later testimony by worker on mains, who turned them off when main put into service. Persons using water-closets would automatically operate valves controlled by seat and thus allow sewage to flow into water main. Each time water main was out of service, only small amt. of water flushed out of line before it was placed back in service, and no attempt made to sterilize it. Levels run on mains and water take-off to Mexican village. Since elevation of water main lower at point of this connection than where stub changed, considerable amt. of sewage would remain in water main after line again in service. We know, from study of recording manometer on distr. system, that uniform water pressure being maintd. under great difficulties. In fact, this led to changes made in distr. lines to include addnl. storage tank near Mexican village. As result of Newton epidemic: (1) State legislature passed new laws giving addnl. authority to State Board of Health to supervise public water distr. systems. (2) Local funds made available for health unit. (3) City plumbing code revised and put in force, elimg. all cross-connections. (4) Water specimens being taken at weekly intervals at designated places in distr. system. (5) Emergency chlorination of city water supply became permanent procedure. *Summary:* (1) Outbreak of more than 3000 cases of dysentery, with several deaths at Newton evidently caused by sewage entering water distr. system of city through frost-proof hydrants and water-closet valves. (2) Failure of water dept. to sterilize or flush that portion of distr. system where changes had been made, led directly to heavy infection of public. (3) Hazardous cross-connections, found in distr. system at times of low pressure, without chlorination, may have been responsible for previous sporadic cases of intestinal disturbance. (4) Great no. of war workers absent from their jobs for several days; unknown no. of soldiers and civilians infected; ordinary business of city disrupted for period of 3 days; and important transcontinental trains, many of them troop trains, delayed avg. of 1 hr. while taking water at nearby safe supply. (5) With institution of proper public health protection measures, epidemic quickly subsided with no further outbreak of cases reported from city.—*Ed.*

Recommendations of Joint Committee on Rural Sanitation—Rural Sewage Disposal. ANON. U.S. Pub. Health Rpts. **58:** 417 (Mar. 12, '43). Of all factors influencing health in rural and urban areas where public sewers unavailable, none of greater importance than proper disposal of human excreta. Typhoid, dysentery and diarrheal types transmitted by contact through fecal contamn. of food and water, largely due to improper disposal of human wastes. Latter must be disposed of so as *not* to: (1) contam. any drinking water supply; (2) cause public health hazard by accessibility to insects, rodents or other possible carriers coming in contact with food or drinking water; (3) cause nuisance by odor or unsightly appearance; (4) pollute or contam. waters of bathing beach, shellfish breeding ground or stream used for public or domestic water supply or for recreational purposes; or (5) violate laws and regulations governing water poln. or sewage disposal.

Com. studied various sewage disposal devices for rural area use and made recommendations according to water-carriage and non-water-carriage methods. Included under former: septic tank, subsurface disposal field, seepage pit, dry well and cesspool. Under latter: chem. toilet, earth pit, masonry vault, pail or can and cremating latrine or incinerator type privies. Adequate inspection of all features presupposed. Use of substitute materials necessary, in some instances, in lieu of recommended materials to conserve critical materials. Most satisfactory and convenient water-carriage system one of piping through which all sewage and domestic wastes conveyed by water flow from origin in human habitation to disposal point. Most efficient method of disposal from individual dwellings and public bldgs. in rural areas without public sewerage system adequate sized septic tank with properly designed field system for effluent disposal according to local needs and soil type. Where only very restricted yard or lot areas available, seepage pits or combination of subsurface disposal fields and seepage pits, or even cesspools with seepage pits must be designed. Tight clay soils offer perplexing problems re safe and satisfactory disposal, often serious where no. of dwellings contemplated on adjoining lots where individual disposals proposed for subdivision developments. Soil conditions must be carefully checked by percolation tests to det. porosity, an important consideration in design to prevent satd. soil conditions possible to result in public health hazards. Design of any individual sewage disposal system must consider location in relation to wells or other water supply sources, topography, soil conditions, area available and max. living capac. of bldg. served. Where soils impervious and suitable unobstructed yard area limited, must consider constructing public or community sewerage system. Plumbing system, grease interceptor, bldg. drain and sewer described. Function, location, design and other features of septic tanks, field distr. boxes, surface disposal fields, disposal trench, seepage pit, dry well and cesspool detailed. Majority of engrs. consider septic tank with subsurface disposal field most satisfactory method of sewage disposal from small installations and isolated rural bldgs. where public sewers unavailable. Contrary to general belief, septic tanks should not be depended upon to remove disease-producing bacteria from sewage. Liq. capac. should be based on daily sewage contribution per capita in: dwellings, 50 gal.; camps, 25 gal.; and day schools, 17 gal. These provide space for 2-yr. sludge accumulation and addnl. vol. equal to 24-hr. sewage flow. Min. size tank, however, 500-gal. field distributing box or chamber box receiving septic tank effluent and from which sewage enters subsurface absorption lines, permitting regulation flow into latter and inspection of tank effluent qual. Constr. detailed. Subsurface disposal system open-jointed one of pipes or drains through which sewage effluent distributed beneath ground surface for absorption into soil. Design feature detailed. To make soil percolation test: (1) Excavate hole 1′ square to depth of proposed disposal trenches, not exceeding 36″. (2) Fill hole with water at least 6″ deep and allow to seep away. Judgment required in detg. how test soil conditions vary from yr.-round avg. Where soil exceptionally dry or conditions questionable, use greater water depths or repeat test. Make no tests in filled or frozen ground. Where fissured soil formations encountered make tests only as directed by and under supervision of state health dept. representative. (3) Minutes required for water to seep away completely, divided by total in. of water placed in hole, gives avg. time required to drop 1′. This value referred to table showing effective absorption area each individual system requires per person for residences, camps or schools. Items under non-water sewage disposal methods detailed according to function, location, constr. and other considerations in specific cases.—*Ralph E. Noble.*

Physical Examination of New Employees to Meet Wartime Conditions. H. B. Bardwell. Ed. Elec. Inst. Bul. **11:** 225 (Aug. '43). Indus. accident prevention receiving greater attention directed toward education of employees and pre-employment mental and phys. fitness. Complete mental and phys. examn. recommended which includes communicable diseases and x-rays to discover other defects which might handicap employee or render him poor risk from workman's compensation standpoint. Pre-employment examn. of greater importance now due to hiring of older workers and 4F's for replacement of younger men entering military services. Maint. of employee's health increasingly important during manpower shortage. Periodical phys. examn. of all employees and follow-up to assure correction of defects and abnormal conditions recommended. Suggests that non-

occupational sickness and injuries present vast field for human eng. by our safety engrs. —*H. J. Chapton.*

Fluorine Dosage in Public Water Supplies. ANON. Wtr. & Wtr. Eng. (Br.) **47:** 404 (Sept. '44). Opinions as to value of fluorine dosage in water supplies not in accord. Norman J. Howard has stated case in which sodium iodide added to water supply to reduce goiter had, by chem. reactions, achieved reduction of its own value. Medical evidence is in favor of fluorine dosage. In England dental fluorosis first noted in '28 and '33 at Maldon. At Tientsin Clark reported for '34 on suspected presence of fluorine in artesian well supplies. Investigation into dental fluorosis is being carried on in U.S. In Mich. survey by Dept. of Health in progress. N.Y. State Dept. of Health has decided to test efficacy of sodium fluoride added to public water supply in arresting decay in children's teeth. Canada also beginning to be interested in fluorine question. Ontario Dept. of Health, in collaboration with Toronto Univ., undertaking survey to det. effect of fluorine in soil, water and food in retarding dental decay. —*H. E. Babbitt.*

Research and Control. NORMAN J. HOWARD. Can. Engr.—Wtr. & Sew. **80:**12:16 (Dec. '42). Credit for reducing toll of water-borne diseases should be shared equally by health officers and san. engrs. Infective organisms reported in sewage effluents for long periods after epidemics of water-borne disease brought under control among contributing pops. In one instance, pathogenic bacteria present in considerable numbers 2 yr. later. This provides strong argument in favor of continuous disinfection of sewage effluents. Investigations made by Metropolitan Water Bd., London, Eng., some years ago showed that uncultivated typhoid bacilli, i.e., those discharged directly by typhoid fever patients or carriers, die more readily in water than typhoid bacilli which have been grown on artificial media. Raw river water was contamd. with urine of typhoid carrier and exposed to sunlight in large concrete tank erected in open air. Concn. of typhoid bacilli was reduced from 770,000 per ml. to 4 within 1 wk. and cultures made after 14–28 days neg. Cultivated typhoid bacilli survived for 5 wk. under comparable conditions.—*R. E. Thompson.*

Sanitation in Latin-America. GORDON M. FAIR. Eng. News-Rec. **130:** 210 (Feb. 11, '43). Interesting acct. of activities of Div. of Health and Sanitation of Office of Inter-American Affairs, to which author consultant. Success of program of exploiting hemispherical resources predicated upon adequate protection of workers in tropical areas against hazards of environment. For instance, to increase production of rubber and permit resettlement of Amazon Valley, control of malaria imperative. In Brazilian reaches of Amazon, malaria control organization of Brazilian Govt. and International Health Div. of Rockefeller Foundation already in existence and hitherto unknown feat of completely eradicating malaria-carrying mosquito, *A. gambiae*, accomplished. Such complete success in whole Amazon Basin hardly expected, but every known means of treatment and control will be employed. General sanitation—water supply, waste disposal, etc.—must, of course, accompany malaria control work. Similar smaller projects under way in other regions of Americas.—*R. E. Thompson.*

Court Decision on Public Health. *Public Water Supply—Protection Against Pollution—Reasonableness of State Board of Health Regulations.* U.S. Pub. Health Repts. **58:** 1666 (Nov. 5, '43). (N.H. Supreme Ct., Willis *v.* Wilkins *et al.*, 32 A. 2d 321; May 4, '43). Town of Pembroke obtained pub. water supply from certain great pond. Petitioned N.H. State Bd. of Health for water supply regulation under statutory provisions, alleging pond contamn. potential. Subsequently, bd. prohibited swimming and bathing in pond and forbade erecting and maintg. structure upon pond ice. Riparian owners sought to have regulations declared void and requested equitable relief. Ultimately case reached state supreme ct. which held: (1) rights affected comprised those which plaintiffs enjoyed primarily as members of pub. along with certain incidental rights possessed as riparian owners, even though lands might be less valuable because such rights curtailed; (2) unimportant that formal notice of investigation by state bd. of health not served upon plaintiffs as riparian proprietors; (3) plaintiffs' contention that bd. erred in not granting certain requests for findings of fact and rulings of law was without right and bd. could adopt summary procedure if desirable; (4) immaterial that certain bd.

members participating in final deliberations did not hear all testimony at both hearings, as bd. could act on own inspection and knowledge, not obliged to hear any party, and could obtain information from any source in any way; and (5) according to record, plaintiffs failed to show bd. acted illegally as to jurisdiction, authority or law observance. Ct. also held, however, regulations could not stand if indisputably unreasonable. Evidence re self-purif., lowered intake, and chlorination, etc., excluded by master as immaterial. Importance of pub. benefit which regulations sought to promote should be balanced against seriousness of restricted private right to be imposed. New trial ordered.—*Ralph E. Noble.*

Alkyldimethylbenzylammonium Chloride as a Sanitizing Agent for Eating Utensils. RONALD M. MACPHERSON. Can. Pub. Health J. **35:** 198 ('44). Tests carried out in food-dispensing establishments, hotels and one hospital (where there were cases of measles, scarlet fever, whooping cough and possible meningitis) showed that hand-washed eating and drinking utensils can be effectively sanitized by rinsing them in aq. soln. contg. alkyldimethylbenzylammonium chloride in concn. of 1 : 5000. Concns. of this product do not seem to be greatly affected by addn. of org. matter. Ice cream scoops can be effectively sanitized by use of this chem. Disinfecting value of product does not appear to be affected by prolonged periods of use. Test kit devised for field detn. of concn. of chem. in rinse solns. as follows: to 0.5 ml. of rinse soln. add 2.5 ml. *N* NaOH, shake, add 3 ml. ethylene dichloride or $CHCl_3$, shake, add 0.02% bromothymol blue one drop at a time and shake after each addn.; end-point reached when aq. layer remains blue.—*C.A.*

Progress Being Made by Federal or State Authorities on Regulations Pertaining to Railway Sanitation. H. W. VAN HOVENBERG ET AL. Am. Ry. Engr. Assn. **45:** 441: 48 (Nov. '43). Reference made to Drinking Water Standards and *Sanitation Manual for Land and Air Conveyances in Interstate Traffic* as promulgated by U.S. Public Health Service on Dec. 3, '42. Program for research on excreta disposal from cars at terminals and yards outlined.—*R. C. Bardwell.*

FOREIGN WATER SUPPLIES—GENERAL

Water Supply—Economic and Social Influences. DELWYN G. DAVIES. Surveyor (Br.) **103:** 247 (May 26, '44). (*Abstracted,* Jour. A.W.W.A. **36:** 1011 ('44).) *Discussion.* Wtr. & Wtr. Eng. (Br.) **47:** 350 (Aug. '44). P. PORTEOUS: Author has striven to formulate generalizations from statistics which, being affected by so many imponderables, not capable of simple interpretation. For example, is it not misleading to postulate from flimsy evidence that "we may expect per capita consumption increase of about 0.375 gpd. (Imp.) for each 1% increase in proportion of dwellings with baths?" Statement that water supplied by Metropolitan Water Board safest in world will no doubt evoke some modest claims from undertakings in other parts of country. G. PEAT: Dairy farming probably greatest consumer of water in agric. industry. Figures given by author as daily needs of dairy cow, viz., 40 to 50 gpd. (Imp.), seem very high. Meters installed, unknown to consumers, on supplies to several modern dairy farms in south of Scotland in '43. Where water from cooler run to waste, consumption per cow was between 25 and 30 gpd. (Imp.). Where not run to waste, 15 gpd. (Imp.) found sufficient. Author gives figures of 2000 gal. (Imp.) per mi. as loss in pipe reticulation. In rural part of writer's area where there are approx. 30 mi. of pipe per 1000 persons, much lower loss occurs in relatively new distr. system.—*H. E. Babbitt.*

Water Supply Control and Development. ALFRED B. E. BLACKBURN. Surveyor (Br.) **103:** 361 (July 28, '44). National water supply service would be assured through Public Water Supply Board, assisted in each region by Dist. Public Water Supply Board with members elected by statutory water supply undertakings in region. Principal defect of existing system is that there is no single body charged with co-ordinating various river interests to assure that rivers used to best advantage of all. Debatable whether in national interests all power of central water authority should vest in Minister of Health.

Some assert that only solution worth putting on statute book is complete nationalization of water sources and supplies. Most of us concerned with immediate future and difficulties of maintg. adequate supplies. There will be 3 periods facing us: (1) When war contracts cease and mfrs. have to change to peacetime work. (2) When industry will be unable to cope with work required and competition to get orders filled will be intense. (3) At some time in future industry may be in position to overtake areas and supply will exceed demand. There is a strong and growing feeling against any postwar system involving a large measure of control by government depts.—*H. E. Babbitt.*

Water Supply: Does It Tend Toward Regionalization? LEWIS COSTLEY. Wtr. & Wtr. Eng. (Br.) **47:** 255 (June '44). Six local authorities within boundary of largest local authority. Storage and distr. of water within this area begun nearly century ago. Most of these 7 local authorities under obligation to afford their supply areas: (a) bulk supplies to adjacent authorities; (b) free supplies to local authorities through whose areas their mains pass; (c) supplies to isolated premises which stand near their mains; (d) free supplies to estate premises through which their mains traverse. Doubtful if all local authorities could supply their compulsory obligations. Close co-operation has developed between most authorities. Need for addnl. supplies acknowledged. Recommendations: (1) *Administration:* (a) separate council to be elected by local authorities; (b) consolidation of private acts to be explored; (c) committee of tech. advisers. (2) *Management:* (a) supply; (b) distr. (3) *Finance:* (a) control of expenditures vested in council; (b) some form of preferential rating to be followed by common rate over whole area.—*H. E. Babbitt.*

Watersheds and Local Governments. C. G. LYNAM. Engineering (Br.) **158:** 115, 144 (Aug. 11, 25, '44). Water supply only one of many eng. and local govt. problems which finally affect and are affected by regime of a river. Only one topographical unit which is self-contained and in which these problems can be solved completely and that is watershed of river. Imperceptibly, but continuously, peak floods of British rivers become higher from decade to decade and concomitant dry weather flow lower. Use of water power always affects river's regime to some extent. Water supply, sewerage and sewage disposal form single problem. Fishery conservation minor matter. River crossings of interest to watershed and responsibility for them must lie on regional authority. Even on trunk routes natl. govt. could confine itself to indicating areas to be served and leave details of design and site of river crossings to regional authority. Most large ports lie on rivers. Even canals lie mainly in one valley. French depts. based on rivers. One striking result of growing centralization of govt. has been increase in number of *ad hoc* authorities. Increase greatest present menace to liberty. Essence of democracy that questions of purely local interest should be settled by those concerned. Delegation of responsibilities to regional authorities would greatly relieve pressure on natl. govt. Installation of regional system would entail abolition of all existing local boundaries which would be no bad thing for few of them have any geographical, economic or social basis. To abolish existing local authorities would not be as difficult as might be imagined. Main difficulties are personal ones. Civ. engr. must help in directing this spirit of change to useful and practical ends.—*H. E. Babbitt.*

Sewerage in Relation to the National Water Policy. R. G. MURDOCH. Surveyor (Br.) **103:** 273 (June 9, '44). Of 4 broad objectives proposed in national water scheme, 2 concern sewerage and sewage disposal. These are: (a) further extension of public water supplies and sewerage in country dists. and (b) better management of rivers which will include prevention of poln. of rivers. Proposed grant-in-aid provides for sewerage as well as water supply. Experience shows that small treatment plants serving 25 to 100 houses frequently have deleterious effect on streams by reason of inferior effluent passed to watercourses. Most desirable that sewerage schemes be considered on regional basis so that existing evils not perpetuated. Numerous inland waterways contamd. by stormwater overflows constructed on combined sewerage systems. If overflows could be restricted to main sewers, many short local rainfalls of high intensity could be accommodated in large sewers where spare capac. would be available. Solution would be simple if separate system could be substituted for combined system.—*H. E. Babbitt.*

Rural Water Supplies and Sewerage. ANON. Surveyor (Br.) **103:** 282 (June 16, '44). Rural Water Supplies and Sewerage Bill read third time in House. Stewart said that under bill it appeared that no grant could be made for sewerage works unless needed to support water scheme. Chapman said that river poln., land drainage and indus. effluents did not come within scope of bill. Stewart moved amendment making mandatory to supply wholesome water in pipes not only to private dwellings but also to agric. and hortic. bldgs. Amendment negatived. Minister of Health said he was satisfied legislation would bring enormous benefits to countryside within 5 or 6 yr.—*H. E. Babbitt.*

The Sources of Water Supply to the London Area. H. A. P. HETHERINGTON. Wtr. & Wtr. Eng. (Br.) **47:** 335 (Aug. '44). Present sources of water supply to London area: River Thames, River Lee, deep wells drawing from chalk and upper and lower greensand formations, shallow wells and collecting systems in river gravels. Of 313 mgd. (Imp.) supplied by Metropolitan Water Board in yr. ending Mar. 31, '39, 65.2% obtained from Thames, 18.3% from Lee, and 16.5% from wells and Chadwell Spring. Large numbers of factories, flats and offices supplied from private wells, 30 to 40% of rainfall represented by runoff and ground water increment and can, within limits, be abstracted for use. Pumping from underground sources causes local depression in water level immediately adjacent to point of abstraction and has distant effect by causing reduction of runoff from catchment area whence supply derived. Abstraction of water from Thames controlled to allow min. flow of 170 mgd. (Imp.) (subject to modifications) over Teddington Weir. Whole of flow from Lee, except that required for navigational purposes, frequently abstracted. Chadwell Spring, in 1613, probably yielded 10 mgd. (Imp.) or more, whereas now only 0.57 mgd. (Imp.). Flow in certain rivers reduced by pumping from wells. Thames at Teddington probably affected only slightly. Rivers Lee, Cray and Darent undoubtedly affected. That considerably more water absorbed on outcrops of chalk than is pumped from under London evidenced by fact that springs still flow at original sites. More water could be pumped from London Basin than at present but only at expense of flow into adjacent rivers. Direct consequence of uncontrolled pumping from underground sources is reduction in yield of shallow wells, abandonment of a number of them with resulting possible sources of poln. Fall in level has resulted in influx of estuarine water into chalk. Paper emphasizes necessity for establishment of body with powers to regulate abstraction of water from wells.—*H. E. Babbitt.*

The Water Shortage. ANON. Wtr. & Wtr. Eng. (Br.) **47:** 233 (June '44). Rainfall was only 21% of avg. in Mar.; driest Mar. of century, with exception of '29 when no rain fell. Difficulty now is serious shortage of rainfall during last 3 mo. of '43, superimposed on dry period of 3 yr. These seasonal water shortages not natural phenomena and can be averted. In "drier side of Britain" where rainfall is less than avg. for whole country, demands approaching 100% of water resources. National planned system would elim. periodical shortages. Rural parishes hardest hit. Larger towns seem to be all right for present.—*H. E. Babbitt.*

Metropolitan Water Board. Restrictions on Use of Water. ANON. Wtr. & Wtr. Eng. (Br.) **47:** 316 (July '44). In consequence of unusual drought Board suspending until further notice authority to draw or use water: (1) Through or by means of any hose, movable pipe or mech. app. in connection with watering of garden, sports area or allotment; washing of any vehicle; cleansing of any pavement part of street. (2) In connection with fountain or any ornamental purpose. Restrictions do not prohibit use of tap so long as no hose attached to it. Watering gardens by means of watering cans permitted.—*H. E. Babbitt.*

Euglena at Ryton Water Works. A. T. PALIN. Wtr. & Wtr. Eng. (Br.) **47:** 263 (June '44). Outbreak of euglena occurred on Oct. 4, '43, at 9 A.M. Growth must have developed in few hr. Copper sulfate applied in alum soln. to raw water in continuous dose of 2 ppm. (as $CuSO_4 \cdot 5H_2O$). Alum dose raised from 1 to 6 gpg. (Imp.). Treatment not complete success. In meantime expts. carried out on lab. scale with following results: (1) Coagulation and settlement with alum up to 10 gpg. (Imp.) not successful. (2) Water dosed with 5 ppm. Cl_2 and 6 gpg. (Imp.) alum, while another sample dosed with 6 gpg. (Imp.) alone. In chlorinated sample supernatant clear and

colorless, while unchlorinated sample settled poorly and had marked green haze. (3) Four samples dosed with 0, 1, 2 and 5 ppm. Cl_2 and then each with 3 gpg. (Imp.) alum. Remarkable results obtained with 5 ppm. Cl_2. Fact that when treatment not properly applied conditions became as bad as ever established efficacy of process. Euglena become non-motile before alum begins to flocculate. Coagulation and settlement with alum alone will remove less than 50% euglena, even under best conditions. 5 ppm. of Cl_2 added with alum produces good results. Essential to add Cl_2 before or at same time as alum. Copper sulfate added with alum gives practically no more improvement than alum alone. Unfortunate effect of pre-chlorination was taste and odor in final water caused by large numbers of euglena. Activated carbon used in dose of 5 ppm. added to settled water before filtration. Treatment not successful. Higher doses, if applied, would have shortened filter runs. When pre-chlorination introduced to deal with euglena, Cl_2 demand partially satisfied at that point. Hence, with same dose of Cl_2 after filtration higher residuals began to be obtained in final water. After de-chlorination taste almost completely removed. The few euglena present in final water completely bleached. Difficulty of "break-point" chlorination with high doses is that paradoxical situation may arise where slight fall in dose may result in enormous increase in residual. Same might occur where raw water changing, particularly in respect to its ammonia content.—*H. E. Babbitt.*

London's Drought Troubles. ANON. Surveyor (Br.) **103**: 294 (June 23, '44). In statement at meeting of Metropolitan Water Board, Franklin indicated London might be in for its worst drought in 60 yr. If present consumption continued reserves would be depleted by over 100 mgd. (Imp.). All available water would be exhausted before end of Aug. From now on no one would be permitted to use hoses or mech. equip. for watering gardens or sports areas, for washing vehicles of any description, for washing down pavements, etc.—*H. E. Babbitt.*

Water Supply and Sewerage in Northern Ireland. Proposed Regional Authorities. ANON. Surveyor (Br.) **103**: 160 (Apr. 7, '44). Setting up of regional water and sewerage authorities recommended by Planning Advisory Bd. appointed by govt. Committee views that province should be divided into 4 regions. In detg. areas consideration given to existing administrative boundaries. Each region large enough to afford competent technical staff. Authorities should be statutory and consist of representatives of urban and rural councils within region. Indus. undertakings which own private sources of supply should be allowed to continue to use them. Many objections to creation of addnl. taxing authorities. Regional authority should cover expenses by charging each rural and urban authority equiv. to amt. raised through existing local taxes. Would not be feasible to fix flat rate for each regional area.—*H. E. Babbitt.*

Experience With the Cumasina Plant at a Central Drinking Water Supply Plant. BORGOLTE. Gesundh.-Ing. (Ger.) **66**: 305 ('43). Raw water subjected to action of free Ag and Cl liberated in electrolytic cell having Ag plate anodes (two, each 200–250 g.) and cathodes of indifferent metal. This cell designed for flow of 50 cu.m. H_2O per hr. The d-c. voltage used on cell was 65 v. and current 0.3 to 0.5 amp., 4 times as much current as recommended. Water passed into reservoir large enough to permit 6-hr. storage. Cost of Cumasina plant 2000 R.M. and monthly operating cost about 100–110 R.M. Plant in use 3 yr. with hygienically satisfactory results in spite of defective filter operation, leading to turbidity. Reduction in bact. count marked, and completely sterile water can be secured with sufficient holding time. Plant simple and neat and can be operated by unskilled persons. Cost within means of small communities and system should be more generally adopted.—*C.A.*

Problems of the Economics of Power and Water in Western Poland. A. F. MYER. Gas-u. Wasser. (Ger.) **84**: 350 ('41). *Summary of a paper by* H. KEMMER. Z. Offentl. Wirtsch. (Ger.) **8**: 29, 57 ('41). Deals with distr. and supply of gas, electricity and water in western Poland. In some towns, such as Litzmannstadt, no central water supply. 180 water works in country of which 34 in western Poland. As result of low rainfall in this dist., (500 mm. per yr.) little ground water. Town of Posen lies at center of brown-coal mining dist. Water-bearing stratum here 120–150 m. below surface in Miocene brown-coal sands and water under sufficient pressure to rise to surface. Because of its high content of iron humates, not potable. Diagram of arrangement and depth of strata in neighborhood of Posen given.—*W.P.R.*

Finley Water Supply, N.S.W., Australia. J. M. ANTILL. Civ. Eng. (Br.) **38**: 142. Town of Finley in S. Riverina of New South Wales has pop. of 1000. Basis of scheme for 1200 persons. Intake works in Mulwala Canal pass water into 12″ gravitational pipeline which leads to excavated earth storage tank. Raw water fed by duplicate low-lift pumps into filtration plant; duplicate high-lift pumps deliver clear water into elevated town. Rating of low-lift pumps and filters, 160,000 gpd. (Imp.). Reinforced concrete service reservoir has capac. of 250,000 gal. (Imp.) with floor slab 45′ and domed roof 80′ above ground level. All mains laid in fibrolite piping. Apart from 2000′ of 12″ gravitation main, over 6 mi. of reticulation consisting of 6″ and 4″ pipe. House service connections galvanized-iron pipe, min. size ¾″. Cost of works approx. £ 24,000.—*H. E. Babbitt.*

The Water Supply of Brisbane, Queensland. ANON. Wtr. & Wtr. Eng. (Br.) **46**: 511 (Dec. '43). During '41–'42 Brackenridge reservoir completed, considerable lengths of main laid to city and connecting main started between reservoir and Sandgate supply. Reserve supply kept at Lake Manchester to replace large quant. drawn from lake on acct. of low rainfall water pumped from Brisbane R. Avg. daily water consumption per head advanced from 46.23 gal. (Imp.) in '40–'41 to 48.12 gal. (Imp.) in '41–'42. In 1859 water obtained from waterholes and small creek which led to river. In 1863 plans prepd. to secure supply from Enoggera Creek for pop. of 50,000. In 1881 Board empowered to develop source on Gold Creek where 400 mil.gal. (Imp.) impounded. In '06 Allan Hazen recommended all further water requirements be met by development of Brisbane R. source. Lake Manchester placed in commission in '16 with original storage capac. of 5700 mil.gal. (Imp.). In '23 service reservoir with capac. of 13½ mil.gal. (Imp.) established on Tarragindi Hill. In '24 vol. impounded water in Lake Manchester increased to 7000 mil.gal. (Imp.).—*H. E. Babbitt.*

The Water Supply of Brisbane. ANON. Wtr. & Wtr. Eng. (Br.) **47**: 361 (Aug. '44). Water from Somerset Dam used for first time. Consumption during yr. was 6866 mil.gal. (Imp.). With steadily increasing demands filtration plant and trunk mains inadequate. Highest consumption 25.5 mil.gal. on Dec. 1, '42. 14 dead ends connected. 13 mi. of mains cement-lined in place. Addnl. salt water mains laid for A.R.P. services. Water filtered by slow sand plant 1964.44 mil.gal. (Imp.) or 30% of works output. Copper sulfate used intermittently. Heavy infestation of filters by mougeotia not unusual. Principal algae normally inhabiting open beds are spirogyra, cladophora, zygnema, hydrodictyon and pleurococcus. Spirogyra principal agent in deposition of carbonates. Clathrocystis present throughout yr. in Lake Manchester. Rapid filters produced 4637.21 mil. gal. (Imp.) or 70% of yr.'s output. Taste developed noticeably at pH of 5.5, disappeared at 6.5. Causative organisms were actinomyces. No such tastes present in slow sand filter effluents fed with same water. Water treated with chlorine and ammonium sulfate prior to admission to trunk mains. Chlorine residual entering mains is 0.4 to 0.6 ppm.; residuals from 0.02 to 0.05 persist throughout distr. system. Avg. total count for raw water in Brisbane R. 360 with max. of 4800 and *Esch. coli* generally present. For Enoggera Res. avg. was 400 with max. of 1000. Avg. total count for supply to consumers from Brisbane R. works 8 and from Enoggera nil. Avg. hardness of Brisbane R. water 149 ppm. with max. of 170. For Enoggera corresponding figures 40 and 46, with min. of 32. Soda ash used for Brisbane R. water. In June heavy growths of cosmarium appeared on sand surface of filters. For new works 42″ steel main to Ipswich laid. Sluice gates and mchy. required for Somerset Res. could not be obtained, preventing completion until after war.—*H. E. Babbitt.*

Boron in Hot Springs at Tokaanu, Lake Taupo. J. HEALY. New Zealand J. Sci. Tech. **24B**: 1 ('42). Tokaanu hot springs alk. and contain 90–265 ppm. of B_2O_3 and 2200–6000 ppm. total solids. The B_2O_3 content is 3–78 ppm. in spring waters in acid areas near Tokaanu. Steam condensates contain 0.04–0.14 g. B_2O_3 per kg. steam.—*C.A.*

The Baghdad District Water Board. ANON. Wtr. & Wtr. Eng. (Br.) **47**: 366 (Aug. '44). Restriction of imported water supplies coupled with large increase in consumption and unprecedented growth in number of consumers. Board obliged to refuse to make new connections to mains after Mar. 31, '43. Supplies of chlorine and alum maintd. with difficulty. Higher freight charges and inflated costs of handling locally contributed to higher

costs. *Esch. coli* absent from 100 ml. in 97% of 1347 samples and less than 50 colonies per ml. in 96% of samples. No. of houses supplied with unfiltered water for gardens increased from 1025 to 1050. 685 new service pipes laid of which 399 copper and 296 coated steel. No major capital works commenced. Most urgent need is enlargement of Sarrafiya filter works. Main extensions totaled 8477 meters, bringing total to 372.9 km. Permits for importation of materials for capital works continue to be unobtainable. Local wage and material prices still rising. Board has not raised water rates despite inflation.—*H. E. Babbitt.*

Municipal Water Supply in South Africa—Its Origins in a New Country. W. L. Speight. Munic. Affairs **9**: 104: 1 (Apr. '44). In '17 disastrous floods in Umlaas R. put out considerable proportion of Durban water works for some weeks. As result, decided to build new dam at Shongweni on Umlaas R. In '35 water supply adequate for incorporated area of 67¼ sq.mi. derived from Umlaas R. Cost of undertaking was £ 2,316,471. Shongweni dam completed in '27 at eng. cost of £776,000. Max. storage capac. of 2600 mil. gal. with depth of 87′ in river bed and water area of 300 acres. River impounded for distance of 3 mi. Dam 815′ at parapet level and has max. height of 128′. In '35 turbine at hydro-elec. plant attached to water works developed 30 kw. and generated current for hydr. power, pumping and lighting purposes. Heavily silt-laden water of river in flood diverted by weir, with impounding capac. of 150 mil.gal. and max. depth of 28′, just before it can enter reservoir and is diverted to waste downstream. Max. height of dam over foundations is 41′ and its over-all length is 760′, with 400′ spillway and flood-diversion canal of 5100′. 20-mi. Shongweni aqueduct consists of 3¾ mi. of tunnels and concrete conduits and 17¼ mi. of steel pipes from 24 to 30″ in diam., with discharge capac. of 10 mgd. Older aqueducts from Umlaas and Coedmore, which together can carry about 6 mgd. In '35 Camperdown Res. had capac. of 150 mil. gal. and 100-mil.gal. clear-water reservoir. At same time, service reservoir had capac. of 22 mil.gal., with distr. effected in zones to provide domestic pressure varying from 70 to 100 psi. Umlaas R. clarified by coagulation processes. After filtering water treated with chlorine. Liquid chlorine used at Durban since '19. Slow sand filter types used at Umlaas and Coedmore and rapid gravity at Northdene and Shongweni. First reservoir (Berry) built in 1880 in Queenstown. Water led into it through open furrow from Bongolo Poort and distributed to town through pipes. In '05 Bongolo plan embarked upon. Consisted of concrete dam wall 300′ long, 50′ wide at base and 6′ wide at top. Wall built across poort to provide reservoir with capac. of about 1500 mil.gal., which, together with other sources, adequate for needs of town. Pipeline connects Bongolo Res. with Berry Res. and town. Supply proved sufficient except in times of drought. As both these reservoirs placed above level of town, possible to arrange distr. by gravitation. No pumping mchy. necessary and qual. of water so high that no filtration or clarification plant installed. Turbidity of Bongolo Res. during rainy season overcome by using Berry Res. as settling tank. Capital cost of Queenstown scheme was over £ 163,000. Port Elizabeth derives its main water supply from catchment area of about 55 sq.mi. in Uitenhage dist. Country is mountainous and totally uninhabited and thus free from obvious sources of poln. Avg. rainfall 31″ per yr. Bulk, Sand, Plamlet and Van Staaden's rivers flow into four reservoirs yielding 862 mil.gal. Cost of works was over £ 1,500,000. Growing domestic and indus. needs have demanded consideration of Kromme R. 72 mi. away, where modern filtration plant being installed. Wide catchment area claimed by East London municipality which obtains its water supply from Buffalo R., for its water sources come from region of 500 sq.mi. Essential to filter water obtained from this type of river by passing it through slow sand filters capable of handling about 1.5 mgd., which is rather in excess of avg. daily consumption. Possible in this way to build up reserve of up to 4 mil.gal., which is stored in service reservoirs. Calcd. that reserve of unfiltered water is at least 356 mil.gal. Capital investment now about £ 420,000.—*Ed.*

Water Supply in South Africa. Anon. Wtr. & Wtr. Eng. (Br.) **47**: 310 (July '44). Cape Town likely to set new records in water consumption. Highest record occurred on Jan. 11, '43, with 23.106 mgd. (Imp.). Dec. '43 averaged 20.185 mgd. (Imp.) as compared with 19.813 in corresponding period of '42. Foundation stone of new dam for water scheme for Durban laid. Two schemes envisaged at Table Mt., one to supply 35 mgd.

(Imp.) and other 20 mgd. (Imp.). Capac. of main storage reservoir will be 5000 mil. gal. (Imp.) with further 450 mil.gal. (Imp.) behind weir. No munic. water works in many (Natal) communities, each household being dependent on rainfall collected on roof areas. W. M. Campbell suggests small tech. com. be formed for examn. of water supply facilities and resources of small Natal towns and report on these matters, purif. methods, etc., to advise on means of giving effect to policy recommended as result of survey.—*H. E. Babbitt.*

A National Water Policy in South Africa. ANON. Wtr. & Wtr. Eng. (Br.) **47**: 262 (June '44). South African govt. has under consideration bill to provide establishment of National Water Supply Com. and Water Supply Control Board. Functions of com. will include establishment, acquisition and working of schemes for supply of water; advising assisting local authorities in maintg. water supply schemes; and reporting to chief health officer of Union contamn. of domestic water supplies. As bill stands, no munic. council need fear com. will take over water supply undertaking it is operating. Part II of bill lays down that Control Board will control supply of water for domestic purposes by com. and by private enterprises.—*H. E. Babbitt.*

Ground Water Supply in the Union of South Africa. ANON. Wtr. & Wtr. Eng. (Br.) **47**: 411 (Sept. '44). Large portion of Union of South Africa without surface water supplies, while perennial streams few. After detailed geo-chem. study of waters occurring in different geol. horizons, G. W. Bond classifies ground waters of Union into 5 main groups. Govt. proposes to establish Water Supply Com. on lines of Electricity Supply Com. In near future govt. will probably publish Bond's thesis "A Geo-chemical Survey of the Underground Supplies of the Union, With Particular Reference to Utilization in Power Production and Industry."—*H. E. Babbitt.*

Water Engineering in South Africa. ANON. Wtr. & Wtr. Eng. (Br.) **47**: 412 (Sept. '44). Govt. irrigation engrs. have embarked on reclamation of thousands of acres of rich land in Zululand, now inundated by floods. Cloudburst in Nov. destroyed old 500-mil.gal. (Imp.) dam situated at Camperdown, about 30 mi. from Durban. Consequent discoloration of water has demanded increased chem. treatment at cost of £ 90 per day. Bloemfontein has decided to embark on £ 394,000 scheme to augment water supply by raising weir at Mazelspoort. Proposed to declare whole of Modder R. catchment area prohibited region. —*H. E. Babbitt.*

The Water Supply of Durban. ANON. Wtr. & Wtr. Eng. (Br.) **47**: 166 (Apr. '44). From report of city and water engr., H. A. Smith, work commenced on constr. of addnl. 2-mil.gal. (Imp.) reservoir at Stella, at estd. cost of £ 15,000. New water scheme at Table Mt., estd. to cost £ 1,750,000, comprises main dam on Umgeni R. and provides storage of 5000 mil.gal. (Imp.); clarification basins, 2 acres in extent; 25-mi. aqueduct with capac. of 20 mgd. (Imp.); and filtration plant with capac. of 20 mgd. (Imp.) at Durban Heights, with ultimate capac. of 50 mgd. (Imp.). Durban Heights emergency scheme, brought into operation in '40, has eased position of supply considerably. Contract given out for addnl. filter plant of 15 mgd. (Imp.) capac., representing complete 20-mil.gal. main program from Umgeni water scheme. Work has also proceeded on addnl. concrete reservoir giving total of 10-mil.gal. capac. at Durban Heights. Shongweni and Umlaas works satisfactorily maintd. throughout year. Since '19 annual revenue shows increase of 318%. Unit cost in pence per 1000 gal. (Imp.) of water is 15.402d.—*H. E. Babbitt.*

The Army Helps Solve Kenya's Water Shortage. F. BAYLES. Wtr. & Wtr. Eng. (Br.) **47**: 312 (July '44). For almost 2 yr. rains have failed in many dists. of East Africa, particularly in Kenya. Army has embarked on ambitious scheme to make most military camps in Nairobi area independent of munic. water supply. Water surplus to army requirements will be pumped into mains to augment civilian supply. Most streams in area seasonal. There is nothing to dam. Secret lies in provision of boreholes to underground water supplies. Drilling is in hands of East African Water Supply Co. (army engrs.). Nairobi's water consumption about 1.5 mgd. (Imp.) of which army takes 0.3 mgd. (Imp.). Water supply company has met with 100% success in its water supply activities. Notable example was site of large anti-aircraft training center where previously it was considered that underground water supplies were nil. Depths of drilling vary considerably. Avg. drilling depth near 400'.—*H. E. Babbitt.*

History of Water Supply on the Witwatersrand. Anon. Wtr. & Wtr. Eng. (Br.) **47:** 409 (Sept. '44). Birthplace of Rand water supply was Boer town of Johannesburg. Not until end of Boer War and establishment of town council under British rule was more extensive scheme than single munic. supply undertaken. Sources of supply in early days from springs. First suggestion of supply from river came in '01 from Major O'Meara who reported that sound scheme for water derived from Vaal R. Rand Water Board formation proposed in '02 and ordinance to establish it prepd. in '03. Board affords only bulk supplies. Function is to obtain and distribute water to municipalities, Transvaal mines, South African railways, and Victoria Falls and Transvaal Power Co. Only in Mar. '23 that first 5-mgd. (Imp.) unit came into service. Fourth unit, in '34, reached permitted original limit of 20 mgd. (Imp.). Vaal Barrage, 25 mi. below Vereeniging, opened 20 yr. ago, long been outgrown. Vaalbank Dam now main source of supply. Authority obtained in '34 to draw 130 mgd. (Imp.) from this sheet of water, 62 sq.mi. in extent. Dam 135′ high and 1900′ long. Talk of raising dam to flood over 100 sq.mi.—*H. E. Babbitt.*

Swimming Baths in South Africa. Anon. Wtr. & Wtr. Eng. (Br.) **47:** 413 (Sept. '44). Southern Rhodesia State Lottery Trustees have voted £ 67,000 for bldg. of swimming baths in town areas. Further sum of £ 25,000 set aside for swimming baths in country areas. Some under constr.; 5 completed. Hoped 18 new baths will be provided. In future possible that addnl. sums will be voted. Although war has resulted in serious modification, all work not suspended. Since start of war number of new baths completed in country dists.—*H. E. Babbitt.*

It is evident that the federal authorities are giving consideration to an order which will limit or prohibit national conventions. It also now appears that such an order will not interfere with regional or state meetings which involve a minimum amount of travel.

Whenever such an order is issued and appears to have reached the stage of a firm and dependable policy, all members of this Association will be fully advised by mail.

Until such direct letter advice is received from the A.W.W.A. office, members may assume that no change has been made in plans relating to Association meetings.

Jan. 5, 1945